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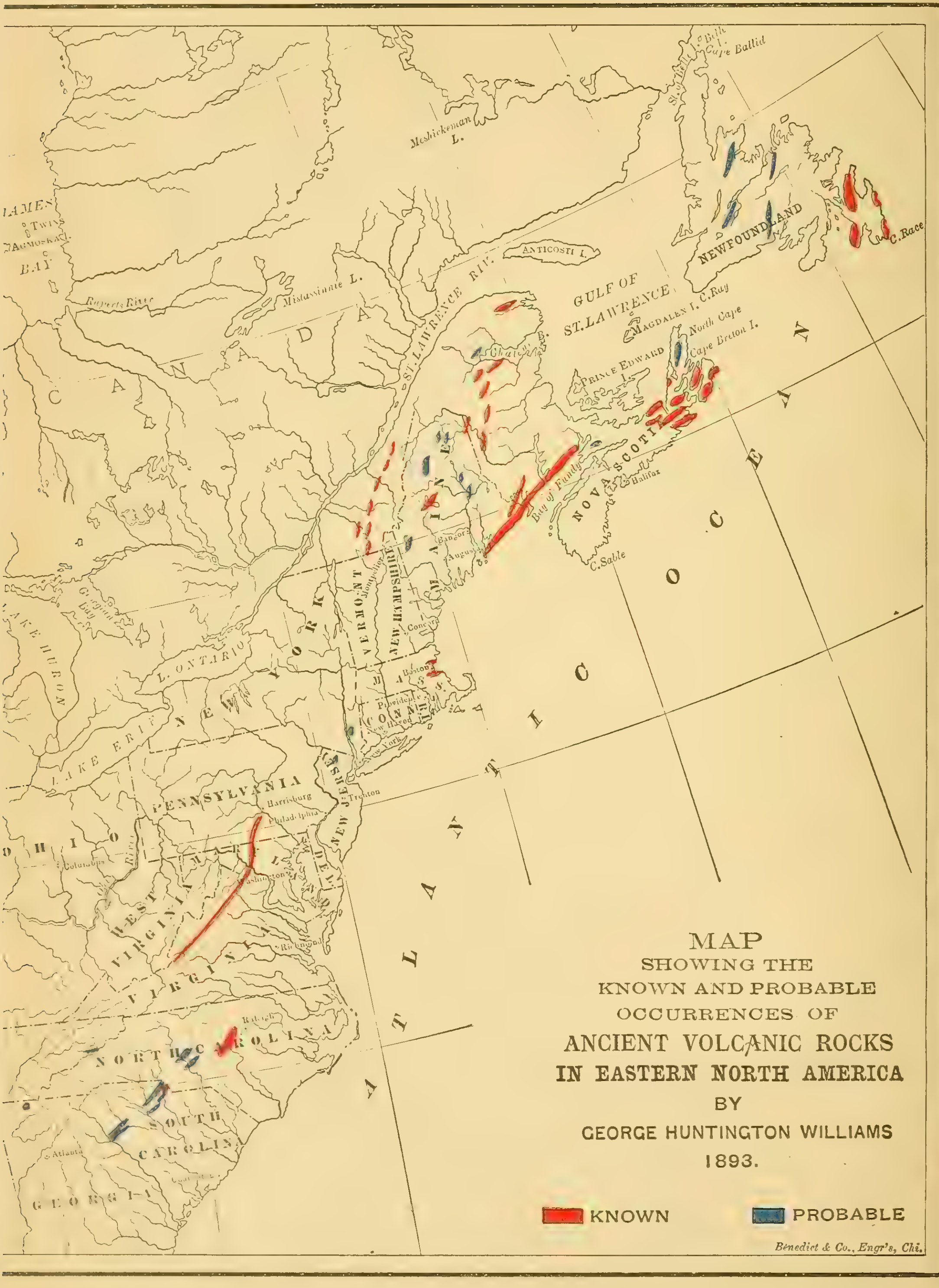

MAP
SHOWING THE
KNOWN AND PROBABLE
OCCURRENCES OF
ANCIENT VOLCANIC ROCKS
IN EASTERN NORTH AMERICA
BY
GEORGE HUNTINGTON WILLIAMS
1893.
KNOWN
PROBABLE
Benedict & Co., Engr's, Chi.
CANADA
GULF OF ST. LAWRENCE
ST. LAWRENCE RIV.
ANTICOSTI I.
NEWFOUNDLAND
C. Race
Cape Ballid
MAGDALEN I.
C. Ray
North Cape
Cape Breton I.
PRINCE EDWARD I.
NOVA SCOTIA
Halifax
Bay of Fundy
C. Sable
ATLANTIC OCEAN
Mistassinne L.
Rupert's River
JAMES BAY
L. ONTARIO
LAKE ERIE
LAKE HURON
NEW YORK
VERMONT
NEW HAMPSHIRE
MAINE
Bangor
Augusta
Concord
Boston
MASS.
CONN.
New Haven
Providence
New York
NEW JERSEY
Trenton
PENNSYLVANIA
Harrisburg
Philadelphia
MARYLAND
Washington
DEL.
OHIO
Columbus
WEST VIRGINIA
VIRGINIA
Richmond
NORTH CAROLINA
Raleigh
SOUTH CAROLINA
GEORGIA
Atlanta

THE

JOURNAL OF GEOLOGY

JANUARY-FEBRUARY, 1894.

THE DISTRIBUTION OF ANCIENT VOLCANIC ROCKS ALONG THE EASTERN BORDER OF NORTH AMERICA.[1]

CONTENTS.

THE great crystalline belt of the Eastern United States and Canada, in spite of all the attention it has received, is probably still the least understood geological province of our continent. Here, almost more than anywhere else, personal adherence to some preconceived theory of the origin and relationships of rocks has biased observation and led to contradictory or unsatisfactory

[1] This paper was outlined at the International Geological Congress in Chicago, August, 1893, and read in full before the Geological Society of America at its Boston Meeting, December 28, 1893.

interpretations of the facts. Only within recent years has detailed and independent work been undertaken in widely separated parts of this vast area, and as yet no sufficient data is at hand for structural, or even for petrographical correlation throughout the whole.

Complete geological maps, showing the structural relations and chronological sequence of all the crystalline formations, are undoubtedly what must be looked forward to as the ultimate aim of work within this region, but the most sanguine will surely admit that we are at present a long way from any such reality. Meanwhile, in the absence of paleontological evidence, the study of the rocks from the point of view of genesis and the establishment of petrographic correlations will do much toward furnishing the positive basis of knowledge upon which final solution of complex structure must rest.

Some of the notions regarding petrographic sequence and the origin of foliation, enforced by masters of geology high in authority, have obscured rather than advanced the problems presented by the crystalline rocks in eastern North America. Not only have we been taught that the mineralogical and structural characters of these rocks are safe indices of their superposition and relative age, but the interpretation of all parallel structures as proofs of sedimentation has led to the conclusion that igneous rocks are rare, if not altogether absent, in these oldest and generally foliated formations of the earth's crust. Now, however, better conceptions are beginning to prevail. No longer do we regard the petrographic character of a crystalline rock as any criterion of its age, while modern methods have enabled us to identify the abundant igneous rocks of ancient times in spite of the misleading structures imparted to them by secondary causes.

Object of this paper.—The present writer has had frequent occasion to insist on the presence of such disguised igneous masses in the oldest geological formations, and to dwell upon the methods by which their origin may be established. In the present paper it is his object to show that not only igneous, but

also *volcanic*[1] rocks are widely distributed through the crystalline belt of eastern North America, and to direct attention to them as offering a new and promising field for work in crystalline geology. For the accomplishment of this purpose it will be necessary (1) to consider the general attitude of geologists in different countries toward ancient volcanic rocks; (2) to specify the criteria available for their identification; and (3) to summarize our present knowledge of where such rocks certainly or probably exist in the eastern crystalline belt. The material embraced under the third of these heads has been obtained from personal work in the field, from a careful study of existing literature, and from unpublished observations and hints furnished by friends.[2]

It is hoped that the bringing together of what is now known of the distribution of ancient volcanic rocks in eastern North America, with the addition of new areas and indication of localities where they may be looked for, will stimulate further work in widely separated portions of this interesting field. These rocks have, it is true, already been correctly described at a few isolated points, but no attempt has before been made to connect such areas or to show their probably widespread distribution. The recent identification by the writer of a very extensive development of pre-Cambrian lavas and volcanic tuffs and breccias in the South Mountain of southern Pennsylvania and Maryland[3]

[1] The term *volcanic* might perhaps be applied with propriety to all rocks produced in or on a volcano, without regard to their structure or coarseness of grain. It is, however, here employed only for effusive or surface igneous rocks, in contrast to such as have solidified beneath the surface, either as the basal portions of volcanoes, or as dykes, sheets, laccolites, or stocks (bathylites).

[2] The writer is especially indebted for help to Professor Eugene Smith, of Alabama; Professor W. S. Bayley, of Waterville, Me.; Professor J. A. Holmes, of North Carolina; Professor H. D. Campbell, of Lexington, Va.; Dr. A. C. R. Selwyn, of Ottawa; Mr. L. V. Pirsson, of New Haven; Professor S. L. Powell, of Newberry, South Carolina, and Mr. Arthur Keith, of Washington. The "Azoic System" of Whitney and Wadsworth, and Professor Van Hise's Correlation Essay on the Algonkian have also proved of much service.

[3] Am. Jour. of Science (3d ser.), Vol. 44, p. 495, Dec., 1892. These rocks have been thoroughly studied by Miss Florence Bascom, whose results may be expected soon to appear in full and adequately illustrated form. See also this Journal, Vol. 1, No. 8, Dec., 1893.

naturally suggested a comparison of these rocks with those of similar character in the Boston basin and eastern Canada, as well as a further search for other regions of the same kind. This search has already proved successful in North Carolina and Maine, while an examination of the older literature indicates many other places where a recurrence of like conditions may be confidently expected.

The proper interpretation and areal mapping of all the demonstrably volcanic regions in the Appalachian crystallines will not only afford much material of interest in the study of petrography and dynamometamorphism, but will also contribute to the differentiation and final understanding of the vast belt of diverse crystalline rocks to which they belong.

DIVERSITY OF OPINION REGARDING ANCIENT VOLCANIC ROCKS.

There is notable in the different countries where geology is cultivated a wide diversity of opinion regarding ancient volcanic rocks. In some regions such rocks have been entirely overlooked or else misinterpreted; in others they are recognized, but are conceived as having been formed under circumstances so different from those which now obtain that they are genetically and inherently distinct from the products of modern volcanoes; in a few only are they considered as having been originally identical with recent effusive rocks, and as differing from them only in alterations due to subsequent causes. This diversity of opinion may be accounted for in part by the varying state of preservation of ancient volcanic material in different parts of the earth's surface or by the lack of experience of field geologists with the characteristic features of modern lavas. It is, however, also due in a measure to the persistence of certain ideas promulgated by early masters of the science in their respective lands.

It was in Great Britain that the real nature of ancient volcanic products received its earliest and fullest recognition. In spite of the absence of active volcanoes from the islands, these rocks have from the earliest days of geological inquiry been favorite

subjects of investigation. From the first, their essential identity with modern volcanic products has been clearly recognized and repeatedly insisted upon—something which we may attribute to the doctrines of Hutton and to the uniformitarian principles of Lyell. Such geologists as Scrope, de la Beche, Sedgwick, Murchison, Jukes, Lyell and Ramsay, speak continually of lava-flows, tuffs, breccias and ash-beds in a way that implies no doubt in their minds as to the existence of volcanoes like those now active, in Paleozoic and pre-Paleozoic times. And more recently the delicate methods of modern petrography have in the same country been first made to establish the identity between ancient volcanic rocks and those of the present. The world is now but beginning to follow in this respect the lead set by Allport, J. A. Phillips, Judd, Bonney, Rutley, Harker, Cole and others in Great Britain. A few Englishmen, like Mallet or Hicks, have considered the oldest volcanic rocks either as originally different from those now produced, or as characteristic of some definite geological horizon, but, on the whole, the British school of geology, more than any other, recognizes a practical uniformity in the nature of volcanic action and products from the Archean to the present.[1]

In Germany and France volcanic rocks (*Ergussgesteine*) are recognized as abundant in certain of the earlier geological formations. Nevertheless there is in these countries a prevailing tendency to separate Tertiary from pre-Tertiary rocks of this class as things originally and genetically distinct.[2] It is noticeable that the earlier schemes of rock-classification, like those of Brongniart, Haüy, Cordier and K. C. von Leonhard, are quite purely mineralogical. The division of older and younger, or paleo- and neo-volcanic rocks is to be in part accounted for by the concentration of these masses in central Europe within the Permo-Carboniferous and Tertiary periods and their comparative

[1] See "The History of Volcanic Action in the Area of the British Isles," Presidential Address by Sir ARCHIBALD GEIKIE, F.R.S., etc. Quart. Jour. Geol. Soc., Vols. 47 and 48, 1891–2.

[2] ROTH: Sitzber. Berl. Ak. 1869, p. 72, *et seq.* ZIRKEL: Lehrbuch der Petrographie, 2d. ed., Vol. I., p. 838, 1893.

rarity in Mesozoic times. It is, however, also connected with the Wernerian doctrine of the non-recurrence of certain physical conditions in the earth's development, as contrasted with the uniformitarianism of Hutton and Lyell. The absence of volcanic types in Europe which serve to bridge over the sharp contrast between those of the Carboniferous and Tertiary, is being rapidly compensated by the discovery of such rocks in other regions. Fortunate finds of even pre-Cambrian lavas so perfectly preserved as to demonstrate their practical identity, both chemically and structurally, with recent products is tending to weaken the old distinction on the continent. There are now many signs of progress toward the idea that the characters regarded as belonging peculiarly to the older effusive rocks are better explained through changes subsequent to their solidification.

Thus Ludwig in 1861,[1] Vogelsang in 1867,[2] and Lossen in 1869,[3] regard some quartz-porphyries as only devitrified glasses, identical with those of modern volcanic regions; Kalkowsky,[4] and recently Sauer[5] and Vogel,[6] have also brought convincing proof that such is often the case.

Gümbel says: "Es scheint in dieser Beziehung denn doch eher gerechtfertigt, zunächst das petrographisch Gleiche auch gleich zu bezeichnen, als in einzelnen Fällen ein neues Princip, das *des Alters*, in die Petrographie einzuführen, welches bei den meisten übrigen Fällen nicht verglichen und berücksicht werden kann;"[7]

And Rosenbusch also remarks:

"Man hat *den geologischen Alter* der Eruptivgesteine bisher ein höheres bestimmendes Moment für die structurelle und mineralogische Ausbildung dieser zugeschrieben als demselben in Wirklichkeit zukommt."[8]

[1] Erl. z. geol. Karte Hessens, Bl. Dieburg, p. 56, 1861.

[2] Philosophie der Geologie, pp. 144–146, 1867.

[3] Abh. Berl. Ak., 1869, p. 85.

[4] TSCHERMAK'S Min. Mitth, pp. 31 and 58, 1874.

[5] Erl. zur geol. Specialkarte Sachsens, Bl. Meissen, pp. 81–91, 1889

[6] Abh. geol. Landesanstalt von Hessen, vol. ii., p. 38, 1892.

[7] Grundzüge der Geologie, 1888, p. 85.

[8] Die massigen Gesteine, 2d. ed., 1887, p. 4.

He nevertheless adheres to the division between paleo- and neo-volcanic rocks, although he says that about their only difference is that the latter can often be found to belong to volcanoes (*i. e.*, volcanic mountains) which are themselves so extremely subject to removal by erosion.[1]

Admirable observations on the use of age in rock-classification are made by M. Neumayr. He says:

"Wohl muss der Geolog dem Alter der Gesteine Rechnung tragen, aber diese Berücksichtigung ist eine von der Beschreibung und Eintheilung der Gesteine durchaus unabhängige Sache. Wie schon oft betont worden ist, ist unter den Sedimentärgesteinen das richtige Prinzip schon durchgeführt, dass man von Kalken, von Dolomiten, Sandsteinen, etc., des Silur, des Jura, des Tertiär spricht, ohne die verschiedenalterigen Gesteine von gleicher Beschaffenheit mit eignen Namen zu belegen; genau in derselben Weise wird man auch mit den Massengesteinen verfahren müssen. Auf einen solchen Standpunkt wird und muss die Gesteinslehre ebenfalls gelangen; sie wird ihre Unterscheidung der Felsarten nur nach petrographischen Merkmalen und petrographischer Methode vornehmen, und die Altersbestimmung der Geologie überlassen, was natürlich nicht ausschliesst, dass beide Forschungsgebiete von einer und derselben Person beherrscht werden."[2]

In Belgium we see de la Vallée Poussin in 1885 writing of "Les anciennes Rhyolites dites Eurites,"[3] just as they would in England; while in France the recognized leader in petrographical usage, Michel-Lévy, although he still distinguishes "*roches porphyriques ante-tertiaires*," from "*roches trachytoides tertiaires et post-tertiaires*," expresses himself in regard to the futility of the age distinction in rock nomenclature as follows:

"On voit, par tout ce qui précède, qu'il est nécessaire d'asseoir une classification pétrographique rationnelle sur des faits contingents, indépendents d'hypothèses géogénétiques, et que la considération de l'âge des roches, à ce point de vue, est aussi hypothétique que celle de leurs conditions de gisement dans les profondeurs ou à la surface. Etant donné un échantillon de provenance inconnue, il est indispensible et il est possible de le nommer et de le décrire sans amphibologie. Il n'est possible d'en déterminer, avec certitude et précision ni le gisement ni l'âge géologique."[4]

[1] Ib., p. 6.

[2] Erdgeschichte, Vol. 1, p. 599.

[3] Bull. de l'Acad. roy. de Belgique (3) Vol. 10, No. 8, 1885.

[4] Structures et Classification des Roches Eruptives, p. 34, 1889.

In Scandinavia, if we judge from the most recent publications, there is, in spite of the general adherence to German nomenclature, a fuller recognition of the similarity between ancient and modern volcanic rocks than is to be found in any other part of Europe except England.

On the western coast of Norway, Reusch describes old lava flows of quartz-porphyry and more basic diabase amygdaloids which show spheroidal parting on a large scale due to cooling. These rocks are accompanied by tuffs and breccias which, in spite of subsequent dynamic action, still show their original characters. In one case, on the island of Gjeitung, occurs a deposit of pumice bombs cemented by what is now a chlorite schist.[1]

In Sweden Högbom describes the general distribution of post-Archean (Algonkian) eruptive rocks, many of which bear unmistakable evidence of volcanic character.[2] Otto Nordenskjold assigns the beautiful flow-porphyries and amygdaloids of the Elfdalen region to the same horizon, while he concludes that most of the Hälleflintas of southeastern Sweden (Småland) are surface lavas. He finds in them such well-developed fluidal, eutaxitic, rhyolitic and perlitic structures that they may be regarded as old rhyolites or devitrified obsidians.[3] The probably much younger and still glassy rhyolites of the gneiss area of Lake Mien are described by N. O. Holst.[4]

In Russia Tschernyschew describes from the central Urals many types of eruptive rocks, and among them both acid and basic volcanics of great antiquity, accompanied by their agglomerates, breccias and tuffs.[5]

In America the recognition of the true character and relationships of ancient volcanic rocks has been greatly retarded both

[1] Bömmelöen og Karmöen, pp. 109, 122, and 403, 1888.

[2] Geologiska Fören. i Stock. Förh., Vol. 15, p. 209, 1893.

[3] Bull. geol. Soc. Upsala, Vol. 1, Nos. 1 and 2, 1893.

[4] Afhandl. Sverig. geol. Undersök. Ser. C, No. 110, 1890.

[5] Allgemeine geologische Karte von Russland, Bl. 139, Central Urals. Text 4° pp. 323 and 333, 1889.

by the adherents to the so-called metamorphic school, like Dana, Logan, Rogers, Lesley and Winchell, who fail to find among the ancient foliated crystallines anything beside altered sediments, but perhaps even more by the influence of that most extreme of all Wernerians, Dr. T. Sterry Hunt. While antithetically opposed to the members of the metamorphic school in his notions of lithological character as an index of geological position, Dr. Hunt had in common with them the conviction that the ancient lavas and volcanic breccias, tuffs and ash-beds were normal aqueous deposits. The basic volcanics of eastern North America enter so argely into his "Huronian," and the acid types so largely into his "Arvonian," that his writings may still be used as suggestive of localities where ancient effusive rocks may be sought for.[1]

But there have not been wanting those among the earlier American geologists who have clearly recognized the igneous members of the ancient crystalline formations, in spite of their disguised character. Prominent among them are E. Hitchcock, Emmons, Lieber, Foster and Whitney. Not only the igneous, but the volcanic (surface) character of the Lake Superior lavas has been maintained by Pumpelly,[2] Wadsworth,[3] Irving,[4] Van Hise[5] and the present writer.[6] In Canada igneous rocks have always been regarded abundant in the oldest formations, while the volcanic character of some of them has been insisted on by Selwyn [7] and mentioned by other members of the Canadian Geological Survey. A looseness of usage is, however, observable in some of these reports, where "volcanic" is made synonymous

[1] See: Presidential Address, Am. Assn. Adv. Sci., 1871; Proc. Am. Assn. Adv. Sci., 1876, p. 211–211; Azoic Rocks, 1878; Am. Jour. Science, May, 1880; Mineral Physiology and Physiography, Chap. IX., 1886.

[2] Geology of Michigan, Vol. 1, 1873.

[3] Bull. Mus. Comp. Zoöl., Vol. 7, p. 111, 1880.

[4] Monograph V., U. S. Geological Survey, 1883.

[5] Bull. Geol. Soc. Am., Vol. 4, p. 435, 1893.

[6] Bull. U. S. Geol. Surv., No. 62, p. 192, *et seq.*, 1890.

[7] Report of the Geol. Survey of Canada for 1877–78. A, p. 5. Trans. Roy. Soc. of Canada, Vol. 1, p. 10, 1882.

with "igneous."[1] In the eastern United States Wadsworth was the first to declare for the volcanic origin of the felsites and tuffs in the Boston basin which, through the influence of Hunt's doctrine had, after Hitchcock's time, come to be explained as sediments. To Dr. Wadsworth also belongs the honor of having been the first geologist on this continent to insist on the original identity of these old lavas and pyroclastics with the recent volcanic rocks of the Cordilleras.[2] There is little doubt that the finely preserved ancient volcanic material in the eastern crystalline belt and elsewhere will, when it is adequately studied, finally bring to this opinion most American geologists. If we as yet know little of the extent and distribution of our ancient volcanics, we are at least bound by no traditions to artificial and useless age distinctions, and may freely follow the lead of our English colleagues.

CRITERIA FOR THE RECOGNITION OF ANCIENT VOLCANIC ROCKS.

It is a self-evident proposition that the identification of certain rocks as volcanic products is in no way dependent upon their present association with a recognizable crater or volcanic mountain. By volcanic rocks we understand igneous or pyroclastic material which has solidified or been deposited at, or very near the earth's surface. It is of little moment whether or not it was ever piled into conical mountains. That the rocks themselves bear witness to their origin and conditions of formation is sufficient. The successive effects of erosion on the easily removed volcanic mountains has been so often graphically described[3] that no further reference to the subject is here necessary. If the Eocene or Triassic volcanoes have so disappeared as to leave

[1] For instance, Ells in his "Geology of the Eastern Townships" (Can. Rept. for 1886, J.) speaks of pre-Cambrian rocks as "volcanic" and "plutonic," but enumerates only granite, diorite and serpentine.

[2] Bull. Mus. Comp. Zoöl., Vol. 5, 1879, p. 277 *et seq.*, and Azoic System, ib., Vol. 7, 1884, p. 429.

[3] See, DE LA BECHE: Geological Observer, pp. 526–537, 1851. M. NEUMAYR: Erdgeschichte, Vol. 1, pp. 202–204, 1887. W. M. DAVIS: "The Lost Volcanoes of Connecticut," Popular Science Monthly, Dec., 1891.

only traces of their original forms, what may we expect of those of Paleozoic or Archean times?

On the other hand, the association in dissected volcanic regions of the effusive rocks with correspondingly abyssal types naturally *suggests* that volcanoes may have once surmounted many areas of coarsely granular ancient igneous rocks. As this, however, cannot be proved, only such regions are here considered as yield rocks of unmistakably surface origin.

Again, ancient volcanic rocks may have been subjected to metamorphosing processes severe enough to have destroyed most of their original characters. In such cases, patient study and a careful weighing of all evidence is necessary to decide their origin, and even that may not avail. Igneous rocks may be so altered as to be indistinguishable from metamorphosed sediments, but it many cases where this at first appears to be the fact, some decisive clue may be discovered.

In establishing the volcanic nature of rocks occurring in ancient and more or less crystalline terrains, attention must be given to several different sets of characters. The field relations must be carefully studied and the material collected on the spot and afterward studied in the laboratory. The criteria for deciding on their igneous and volcanic origin may be arranged as follows:

I. If the rocks are *igneous*, whether abyssal or surface, they will:

1. Conform in chemical composition to certain well established types;
2. Show an association of petrographical types which, both chemically and mineralogically, follow the laws of consanguinity.

II. If they are *volcanic:*

1. They may be found in the field to occur in distinct sheets, flows or necks;
2. They will have produced very little or no contact action in the adjoining rocks;
3. They may include irregular fragments of other rocks.

III. If they are *volcanic:*

1. They may appear to be striped, banded, or pseudo-"stratified" conformably to adjoining sedimentary deposits;
2. They will probably be accompanied by fragmental (pyroclastic) material, which may or may not itself be really stratified. Such material will vary greatly in coarseness, containing bombs, agglomerates, breccias, tuffs, sands and ashes. The characteristics of these are:
   1) indiscriminate mixture of all sizes and shapes of fragments;
   2) material of same kind as the igneous rocks;
   3) cement, either finer fragmental material (tuff-breccia) or lava (flow-breccia);
   4) very angular shape of smallest fragments (microscopic glass sherds).
   5) if ancient volcanoes were on the shore-line, such material may have been immediately worked over by water and interbedded with more or less normal aqueous sediments.

IV. Most important of all, however, is the identification of those characteristic structures known to originate only in glassy, half-glassy or very fine grained porphyritic rocks, solidifying at the surface, or in very narrow dykes where solidification has been rapid. These will be found to be very persistent and can usually be identified under the microscope in spite of devitrification, alteration, or even a considerable degree of dynamometamorphism. The most common of these structures are:

1. a vesicular, scoriaceous, pumiceous or amygdaloidal structure;
2. a sharply defined, small porphyritic structure with a glassy, half-glassy or felsitic (cryptocrystalline) base;
3. a spherulitic structure, due to either large or small lithopysæ, hollow spherulites, or compact spherulites,

arranged either irregularly, or in more or less discontinuous bands or layers;

4. a flow structure, produced either by the elongation of vesicles or the parallel arrangement of constituents or crystallites. It may also be produced by the interlacing of different colored magmas (eutaxitic structure);
5. corroded phenocrysts, quartz with embayments, or skeleton crystals due to rapid and imperfect growth;
6. microscopic spherulites, globulites, trichites, crystallites, real or devitrified glass inclusions, quartz with orientated siliceous aureoles, axiolites, etc.;
7. perlitic structure, wholly or partly devitrified.

Although some of these structures may occasionally occur in dykes or other igneous rocks which have rapidly solidified beneath the surface, they are nevertheless so essentially characteristic of effusive lavas, that, in lack of any evidence to the contrary, they may be regarded as fairly safe guides in establishing the effusive nature of rocks. This evidence is beyond doubt, if such rocks are accompanied, as they generally are, by ash material.

While a single one of these characteristics may not be sufficient to identify a volcanic occurrence, many, if not all of them, will be found to occur together, and only in rare instances will it be found that some of them, at least, have not survived the vicissitudes of metamorphism. That many regions in the ancient crystalline belt of the Appalachian system exhibit most of them in great perfection is now well known. It is only a misinterpretation of these characteristic features of volcanic rocks, due to a lack of acquaintance on the part of observers with their recent analogues, that has prevented their recognition long ago. Thus, by those who have heretofore described these rocks as sediments, both secondary cleavage, and the banding due to flow or parallel spherulitic layers have been mistaken for stratification; spherulites have been erroneously regarded as concretions; and the accompanying pyroclastics, as normal conglomerates or slates.

It is the purpose of the writer in the present paper to maintain that *in the great crystalline belt of eastern North America, large areas of volcanic rocks occur, and that these, in spite of their great age, are in all respects the same as modern volcanic materials, save for alterations subsequent to their original formation—among which alterations devitrification has been one of the most important.*[1]

DISTRIBUTION OF VOLCANIC AREAS ALONG EASTERN NORTH AMERICA.

I shall now proceed to summarize the present state of our knowledge of these volcanic areas, as far as they belong to the Eastern or Appalachian crystalline belt, omitting all reference to the central Canadian, Lake Superior, Missouri, or other more western regions of similar nature. In this review I shall commence with Newfoundland and follow them southwest, parallel to the coast.

Eastern Canada.—In a recent comparison between the Eozoic and Paleozoic rocks of eastern America and western Europe, Sir William Dawson says that the Huronian was evidently a coarse marginal deposit, accompanied by abundant volcanic outbreaks, similar to those which occurred about the same time in Wales. He is also confident that many of the bedded Huronian rocks are really of volcanic origin, being ashes in an altered state.[2] In the same paper he mentions volcanic rocks, both lavas and pyroclastics, as abundant in the Ordivician and Silurian formations of eastern Canada.

The reports of the Canadian and Newfoundland surveys abound in references to rocks of a volcanic character in the early Paleozoic and pre-Paleozoic horizons. These references are, however, always purely those of a field-geologist engaged in a rapid reconnaissance. The frequent use of such field terms as felsite, porphyry, trap, amygdaloid, agglomerate, breccia and ash suggest a vast development of contemporaneous volcanic

[1] On the nomenclature of these ancient and devitrified lavas, see Miss FLORENCE BASCOM'S paper, this Journal, Vol. I., No. 8, p. 825, Nov.–Dec. 1893.

[2] Quart. Jour. Geol. Soc., Vol. 44, p. 801, 1888.

materials, but thus far no petrographer has attempted to study systematically either the field or microscopical relations of any area of these interesting rocks. A very broad and interesting field is thus seen to be awaiting investigation in Newfoundland, Gaspé, New Brunswick, Nova Scotia and the Eastern Townships.

Professor J. B. Jukes, in his "Geology of Newfoundland," describes old lava flows and accompanying pyroclastic deposits as very abundant, especially on the peninsula of Avalon, which forms the eastern part of the island.[1] His observations are confirmed by the later reports of Murray and Howley, who agree that the western part of this peninsula was the scene of extraordinary volcanic activity in very early times.[2]

In his three reports on the eastern portion of Cape Breton, Fletcher describes the Ste. Anne, Boisdale, Coxheath, East Bay and Mira Hills, as composed largely of ancient (pre-Cambrian) volcanic rocks, among which felsites of all colors, felsite-porphyries, felsite breccias and amygdaloids abound.[3] Similar rocks appear also to extend up into, and to form an important part of the Cambrian, Silurian and Devonian formations. In a later report on the northern part of Cape Breton, Fletcher[4] finds that the greater part of the northern peninsula is also composed of "felsites," but the petrographical distinctions of both Fletcher and Gilpin[5] are so indefinite that a variety of coarsely crystalline rocks seem to be embraced in this general designation. In describing the Mira "felsites," Fletcher mentions those of Blue Mountain and Gull Cape, near Louisburg, as being "globular," or "concretionary," (coarsely spherulitic?) often presenting "single or united spheroids, the concentric layers of which may

[1] Excursions in and about Newfoundland in 1839 and 1840, 2 vols., 1843. Geology, Vol. 2, pp. 245–341.

[2] Reports of the Geological Survey of Newfoundland for 1868–1881.

[3] Reports of the Geol. Survey of Canada, 1875–76, pp. 369–418; ib., 1876–77, pp. 402–456; ib. 1877–78, pp. 1–32, F.

[4] Ib., 1882–83–84, pp. 1–98 H.

[5] Quart. Jour. Geol. Soc., Vol. 42, p. 515, 1886.

be removed like the coats of an onion." He also speaks of them as "coarsely brecciated" and "vesicular." A point of some interest is Fletcher's conclusion that "both felsite and syenitic strata are intimately associated as part of the same group of crystalline rocks, differing, not so much in composition as in the degree of crystallization they have been subjected to" (*sic*).[1] In greatly eroded regions we should expect to find surface volcanic rocks associated with their coarser abyssal equivalents.

In Nova Scotia proper the best known area of ancient volcanic rocks is in the northeastern corner of the province, near Arisaig, in Antigonish county. These were considered by Sir William Dawson in 1850 as "metamorphic."[2] In 1864, Dr. Honeyman described them as vesicular traps, amygdaloids and porphyries, associated with tufa and tufaceous conglomerate.[3] In his first report on eastern Nova Scotia, Fletcher describes variegated, vesicular and amygdaloidal "felsites" and "fragmentary felsites," like those of Coxheath and Louisburg, associated with "syenite" (hornblende granite) and diorite.[4] These rocks are regarded as pre-Cambrian, and are particularly developed at Arichat, Cape Porcupine on the Straits of Canso, and in the Sporting, North and Craignish mountains. In the North Mountains the felsites are said to pass gradually into syenite (l. c. p. 14). The gradual blending of the felsite and overlying George River limestone is attributed to "common metamorphism," rather than "to contemporaneous volcanic origin or subsequent intrusion" (l. c. p. 17). Nevertheless, at Cape Porcupine the felsite is regarded as possibly an igneous rock, since "the apparent lines of bedding are like those of a furnace slag" (l. c. p. 25). In the subsequent report of the extension of his explorations southward and westward in Nova Scotia, Fletcher admits the volcanic origin of the felsitic rocks of Arisaig, Doc-

[1] Quoted by GILPIN: Quart. Jour. Geol. Soc., Vol. 42, p. 516.

[2] Quart. Jour. Geol. Soc., Vol. 6, p. 347, 1850.

[3] Ib., Vol. 20, p. 333, 1864.

[4] Report of the Geol. Survey of Canada, 1879–80, F.

tor's Brook, Georgeville, Blue Mountain and East River of St. Mary's. These are quite like the Cape Breton and Cape Porcupine rocks, and carry copper, as they do in South Mountain, Pa., and on Lake Superior. He gives the age of these eruptions as probably pre-Cambrian, although at Arisaig they may be of any age older than Medina. Similar volcanic eruptions occur in all strata up to the base of the Carboniferous.[1] In his last report covering Pictou and Colchester counties, the same author describes Cambro-Silurian porphyries, agglomerates, fragmental felsites, breccias and amygdaloids from Moose and Sutherland rivers. A dyke-like mass of volcanic breccia occurs on Sam Cameron's brook. Similar volcanic products are also very apparent in the Devonian of these two counties, among the most interesting of which are the syenitic granites overlaid by thick volcanic deposits at the east end of the Cobequid Hills, as described by Dawson.[2] The well-known traps of northwestern Nova Scotia, along the Bay of Fundy, which furnish the beautiful zeolites and other minerals, are of Triassic age.

In New Brunswick and the Gaspé Peninsula, old volcanic rocks, like those of Newfoundland and Nova Scotia, are extensively developed. Ells and Low mention amygdaloidal traps and porphyries cutting various strata of Gaspé, up to and including the Devonian.[3] Felsitic rocks, similar to those which are better known further to the south, are rather vaguely mentioned by Robb in northern New Brunswick.[4] Ells, in his report on the same region in 1879–80, clearly describes as volcanic both acid and basic rocks. A vast area of felsite, petrosilex, porphyry and breccia, like that near St. Johns, is developed in the upper Nipisiguet river and lake Nictor. Another like it extends from the upper Upsalquitch river along Jacket river to the bay of Chaleur, while great masses of basic volcanics (amyg-

[1] Ib., 1886, P.

[2] Acadian Geology, 1878, suppl., p. 79.
Report of the Geol. Survey of Canada, new ser., Vol. 5, 1890–91, P. pp. 147–166.

[3] Ib., 1882–83–84, E. and F.

[4] Ib., 1870–71, p. 245.

daloids, aphanites, etc.) occur around the head of the Bay of Chaleur and Dalhousie, as well as on the upper Upsalquitch and Elm Tree rivers. Many of these rocks are pre-Cambrian, while others cut the Silurian strata.[1] Great sheets of contemporaneous trap are also found by Ells in the Silurian, and to a very small extent in the Devonian, along the north shore of the Bay of Chaleur. Bailey explored parts of northern and western New Brunswick, especially in Carolton, York and Victoria counties, and found porphyries, felsites and amygdaloids, intrusive in the Silurian and older formations in Canterbury, Woodstock and Kent townships, near the St. Johns river.[2] Still later Bailey and McInnes continued similar explorations, and found signs of intense volcanic action in the Niagara limestone at Pointe aux Trembles, and a great development of acid and basic surface rocks near the Aroostook river and at Presqu'ile and Haystack mountain in Maine.[3] The same is true near Tobique lake, farther to the northeast.

As early as 1839, Gesner describes the volcanic rocks along the Bay of Fundy, in southern New Brunswick, as belonging to several distinct horizons.[4] In 1865, Bailey, Matthew and Hartt distinguished two groups mainly of volcanic origin, to one of which, the "Coldbrook," they assigned a Huronian, and to the other, the "Bloomsbury," a Devonian age.[5] In 1872, Bailey and Matthew, after a season's field-work with Dr. T. Sterry Hunt, united the Coldbrook and Bloomsbury groups on purely lithological grounds, and for the same reason joined with them two other volcanic series—the Coastal and Kingston groups—exposed at other localities in southern New Brunswick.[6] The petrographical characters of these rocks were those regarded by Hunt as sufficient demonstration of Huronian age. The acceptance of this fallacious principle exercised a distinctly

[1] Ib., 1879–80, pp. 35 to 42.

[2] Ib., 2882–83–84, G. pp. 15 and 20; ib., 1885, G. pp. 22 and 28.

[3] Ib., 1886, N. pp. 14–15; and ib., 1887–88, M. pp. 32 and 47.

[4] First Report on the Geological Survey of the Province of New Brunswick, by ABRAHAM GESNER. 87 pp. 1839.

[5] Observations on the Geology of Southern New Brunswick. 1865.

[6] Report of the Geol. Survey of Canada, 1870–71, pp. 57–133.

retarding effect on the deciphering of New Brunswick geology. Numerous occurrences of felsite, porphyries and amygdaloids were described between Musquosh Harbor and Loch Lomond, near the city of St. Johns, and along the line between Kings and Queens counties (Coldbrook and Bloomsbury groups). Similar rocks were traced from L'Etang Harbor, near Passamaquoddy Bay, along the edge of the Bay of Fundy to Shepody, in Albert County (Coastal group); and finally, a belt of analogous composition was described between the Long Reach of the St. Johns river and Mace's bay (Kingston group). These rocks were at this time, however, on account of Hunt's influence, united with their associated sediments, and nothing is said about their volcanic character. These authors were forced to regard similar rocks on the shores of Passamaquoddy bay as Silurian, because of associated fossils, in spite of their lithological identity with the "Huronian." These they called the Mascarene series.[1]

Four years later the same authors united the Kingston and Mascarene groups and regarded both as upper Silurian.[2] In a report of the pre-Silurian rocks of Albert, eastern Kings, and St. Johns counties, Ells gives some clear statements relative to the volcanic rocks of southern New Brunswick. He says:

"In their lithological aspect, the rocks forming the southern metamorphic belt present great diversity. Their general character is of two kinds—altered sedimentary and volcanic. * * * In the latter we include the great mass of petrosiliceous rocks, so called, with breccias and other ash rocks, which in places show bedding, but this is often so obscurely marked as to be exceedingly doubtful. * * * Near the contact of the volcanic and sedimentary rocks we find an extraordinary development of generally coarsely crystalline diorites and syenites, which would seem to form the basal portion of the volcanic part of the series."[3]

A report on the same rocks was published at the same time by Bailey, who divides them into a feldspathic, syenetic and gneissic group, including limestones, serpentines, and dolomites

[1] Ib., pp. 144–158.

[2] Ib., 1874–75, pp. 85–89.

[3] Ib., 1877–78, D. p. 3.

(Laurentian); a felsite-petrosilex group (Lower Huronian or Coldbrook); and a schistose, chloritic micaceous group (Upper Huronian or Coastal).[1] The results of all their work on the rocks of southern New Brunswick is summarized by Bailey, Matthew and Ells, with a general geological map in three sheets.[2]

That portion of the Province of Quebec lying south and east of the St. Lawrence is called the Eastern Townships. We have already considered that portion of it composing the Gaspé peninsula. The portion lying west of Maine and north of New Hampshire and Vermont was supposed by Logan to be wholly occupied by rocks of the Quebec Group. In 1879, Dr. Selwyn divided the rocks of this zone into three groups, which he defined as lower Silurian; volcanic (probably lower Cambrian); and crystalline (probably Huronian). The lower of these divisions forms an anticlinal axis extending from Lake Memphremagog to L'Islet County, 150 miles. It contains a great variety of altered sedimentary beds, associated with "diorites, dolerites, serpentines, amygdaloids, and volcanic agglomerates," regarded by Hunt as altered sedimentaries. The second division, said to be intimately related to the last, is largely composed

"especially on the southeastern side of the axis, of altered volcanic products both intrusive and interstratified, the latter being clearly of contemporaneous origin with the associated sandstones and slates."

These rocks are designated as

"dioritic, epidotic, and serpentinous breccias and agglomerates; diorites, dolerites and amygdaloids holding copper ore; serpentines, felsites and some fine grained granitic and gneissic rocks."

They are especially developed along the contact of the last-mentioned group, of which they "may be merely the upward extension."[3] In a later paper on the Quebec Group, Dr. Selwyn considers these volcanic rocks thoroughly from the English point of view. He says:

[1] Ib., DD. p. 2.

[2] Ib., 1878–79, D. p. 26.

[3] Ib., 1877–78, A. pp. 5–9.

"I would also submit that neither a schistose nor a bedded structure can be accepted as proof of a non-igneous or volcanic origin, and that a once massive lava-flow, whether augitic or feldspathic, is as likely, through pressure and metamorphism, to assume a schistose structure as are ordinary sedimentary strata. It is, I am aware, not in accordance with generally received ideas on the nature of ancient igneous rocks to suppose they can be schistose and stratified, especially so in America, where volcanic agency in the earlier geological periods has been almost entirely ignored, and all those rocks which by their microscopic characters and chemical composition, and by their geological associations and relations, point to volcanic agency as the cause of their formation, have been said to be '*not igneous, but metamorphic in origin*,' a description which, it seems to me, is decidedly self-contradictory." [1]

Selwyn later again maintained his volcanic group, and published microscopic descriptions of some of its rocks (quartz-porphyry and porphyrite) by Adams.[2] Little or nothing is added to our knowledge of the strictly volcanic rocks by the two subsequent reports on the geology of the Eastern Townships by Ells.[3]

The recognition of ancient volcanic rocks in the United States is far behind that which prevails in Canada. This, as has already been pointed out, is due to the influence of so-called "metamorphic" ideas, or more properly to the Wernerian doctrine, that every rock showing any foliated or parallel structure is sedimentary.

New England.—Very little definite information can be gathered from the earlier reports on the geology of Maine, by Jackson and C. H. Hitchcock, regarding the old volcanic deposits. Jackson frequently uses such petrographical terms as "amygdaloidal trap, ribbon jasper, clinkstone porphyry, and breccia composed of an infinity of fragments of jasper," in describing the rocks near Eastport and Machiasport, on the Maine coast. He regarded the basic rocks (trap) as eruptive, but the "jasper" as semifused sediments whose lines of stratification were still pre-

[1] Trans. Roy. Soc. Canada, Vol. 1, p. 10, 1882.

[2] Report of the Geol. Survey of Canada, 1880–82, A. p. 2 and pp. 10–14.

[3] Ib., 1886, J., and ib., 1887–88, K.

served.[1] His descriptions are, however, very suggestive, especially in light of the truly volcanic rocks which have been recently discovered in the older strata of Maine. C. H. Hitchcock, in his Maine reports, regards the acid volcanic rocks near Machiasport as altered slates, and mentions extensive areas of similar rocks on Moosehead, Portage, Long, and Chamberlain lakes, as well as along the Aroostook and Penobscot rivers, in the interior of the state.[2] Goodale gives four patches of analogous "siliceous slates" in York county, and five in Oxford county, and J. H. Huntington describes the summit of the diorite southeast of Kennebago lake, in western Maine, as composed of compact felsite, which he regards as an eruptive rock.[3] The first definite descriptions of ancient volcanic rocks in Maine was given by Professor Shaler, who examined the regions about Eastport and Mount Desert. Near Eastport, and especially on McMaster's island, three types of volcanic material are largely developed: 1) detrital accumulations which have fallen through the air; 2) true lava flows; 3) dykes. They seem to belong to various horizons of Silurian age.[4] A similar series of interstratified volcanic breccias, lava flows and ash beds are described as forming a large part of Mt. Desert island south of Southwest Harbor, and the Cranberry Isles.[5]

The writer has had the opportunity to personally examine the volcanic rocks of the Mt. Desert region, and he is indebted to Professor W. S. Bayley of Waterville, Me., for specimens and slides of the beautiful lavas of Vinal Haven, and to Mr. E. B. Mathews for notes and specimens of similar rocks from Mt. Kineo on Moosehead Lake.

Along the shores of Cranberry Island occur hard jaspery felsites, often porphyritic, and exhibiting such characteristic features of glassy rocks as spherulites, single and in bands, flow-

[1] First Report on the Geology of the State of Maine, 1837, p. 12 and pp. 36–42.

[2] Geological Report, 1861, p. 190, and p. 432; also ib., 1863. p. 330.

[3] Proc. Am. Assn. Adv. Sci., Vol. 26, p. 286, 1877.

[4] Am. Jour. of Science (3d ser.), Vol. 32, pp. 40–43, 1886.

[5] Eighth Ann. Report U. S. Geol. Survey, pp. 1037, 1043, 1054. 1889.

structure, etc., in great perfection, although all trace of the original glass has long since disappeared. The rocks collected by Professor Bayley on the north side of Vinal Haven and on the opposite shore west of North Haven are, according to his field observations, all surface flows or tuffs. Of the nine specimens kindly submitted to me for examination by Professor Bayley, one is a medium grained microgranite and all the others

FIG. I.

FIG. I. Devitrified glass-breccia from north side of Vinal Haven, Penobscot Bay, Me. Magnified six times.

are devitrified glassy rocks, which were once either obsidians, glass breccias, or tuffs. No. 94 is a banded flow-felsite, a devitrified glass with narrow chains of spherulites. No. 100 is a devitrified obsidian containing delicate flow-lines produced by trichites, some zircon crystals, and spherulitic bands in which epidote has been secondarily produced. No. 126 is a pale gray felsite containing large round nodules which may be spherulites. Under the microscope it shows a pronounced perlitic structure. These rocks contain spherulitic structures which are not devitrification products but original, if we may judge from their absolute identity with similar structures in the glassy rocks from Obsidian Cliff. The other five specimens are fine grained vol-

canic ashes, most of them composed of very sharply angular fragments of devitrified glass or pumice with beautiful flow structures. The delicate detail produced by trichites in one of these is rather roughly represented in Fig. 1. It is not unlike the devitrified glass-breccia described by the writer from Onaping river in the Sudbury district.[1]

The specimens collected by Mr. Mathews at Mount Kineo on Moosehead Lake, and kindly loaned me for examination, are typical quartz-porphyries or keratophyres, some of which exhibit such perfect and delicate flow-lines that they can be regarded only as devitrified glassy lavas.

In New Hampshire felsites and quartz-porphyries abound. They were regarded as eruptive by Hitchcock and by Hawes when they occur in dykes, although the latter regarded many of them, especially when interstratified, as sediments fused *in situ*.[2] There are as yet no published descriptions which make it reasonably certain that truly volcanic, as contrasted with abyssal igneous rocks, occur within this state.

The important development of ancient volcanic rocks in eastern Massachusetts, in the neighborhood of Boston, has been more discussed than any other similar region on this continent. An excellent résumé of the development of opinion regarding these rocks has been given by Whitney and Wadsworth.[3] E. Hitchcock held correct views as to the igneous character of all the massive rocks, although he regarded the amygdaloids and some of the apparently stratified felsites as altered sediments. Later the influence of Hunt created a general impression that the greater part of these rocks—even the granites—were of sedimentary origin. Wadsworth was the first to successfully combat this idea, and to show that not only were the coarsest massive rocks igneous masses, but even the finer jaspery felsites and their

[1] Bull. Geol. Soc. Am., Vol. 2, p. 138, 1891.
Report of the Geol. Survey of Canada, 1890–91, F. p. 75.

[2] See Geology of New Hampshire, Vol. 2, p. 260, and Vol. 3, part IV., Mineralogy and Lithology, p. 171, 1878.

[3] The Azoic System, pp. 398–440, 1884.

accompanying fragmental materials were the products of ancient volcanic action. He maintained that the felsites of Marble Head were merely altered rhyolites which had once been quite like those of the western Cordilleras ; and their banding was flow-structure ; and that they were accompanied by ash beds which he called *porodites*.[1] Two years later the detailed work of Diller and Benton established the volcanic character of the felsites of Medford, Melrose, Malden, Sangus, Wakefield and Lynn, and of the amygdaloid of Brighton.[2]

Other areas of similar rocks occur near Newburyport, and also to the south of Boston at Needham, Dedham, Milton, Blue Hill, Hingham, Nantasket and Manomet,[3] but these have not as yet been so carefully examined as those farther north, although Crosby, in his recent " Geology of Hingham," classes the melaphyre. porphyrite, and felsite of Nantasket and Hingham as effusive or volcanic rocks, and describes the latter as "undoubtedly an ancient, devitrified obsidian."[4]

The Middle Atlantic States.—In New York state there are, as far as the writer is aware, no remains of igneous rock which have solidified at the surface. Nevertheless, the isolated and

[1] The Classification of Rocks. Bull. Mus. Comp. Zoöl., Harvard Coll., Vol. 5, p. 282, 1879. It is worthy of note, in view of all the erroneous ideas that have prevailed regarding the Boston felsites, that as early as 1822, Dr. Thomas Cooper, President of the College of South Carolina, in an article on "Volcanoes and Volcanic Substances" says : " No person accustomed to volcanic specimens can look at the porphyries from the neighborhood of Boston, in my possession, and doubt of their volcanic origin." (Am. Jour. of Science, 1st ser., Vol. 4, p. 239).

[2] "The Felsites and Their Associated Rocks North of Boston," by J. S. Diller, Bull. Mus. Comp. Zoöl., Vol. VII., p. 165, 1881 ; and "The Amygdaloidal Melaphyre of Brighton, Mass.," by E. R. Benton, Ph.D., Proc. Bost. Soc. Nat. Hist., Vol. 20, pp. 416–426, 1880. The writer is indebted to Mr. Diller for the privilege of examining his collection of slides of the Boston rocks which are in all essential respects identical with those from the coast of Maine, from South Mountain and North Carolina.

[3] E. Hitchcock : Final Report on the Geology of Massachusetts, Vol. 1, p. 150, 1841 ; W. O. Crosby : Geology of Eastern Massachusetts, pp. 79–95, 1880.

[4] Proc. Bost. Soc. Nat. Hist., Vol. 25, p. 502, 1892. See also by the same author : The Lowell Free Lectures on the Physical History of the Boston Basin, 1889 ; and the Geology of the Boston Basin, Vol. 1, Part 1. Occasional Papers of the Boston Soc. Nat. Hist., IV., 1893.

highly differentiated "Cortlandt Series," near Peekskill, presents us with the deeply eroded roots of an ancient volcano, probably of Cambrian or Silurian age, whose superficial parts have entirely disappeared.[1] The eleolite-syenite area in northern New Jersey is probably of the same character.

In Pennsylvania and Maryland we find in the South Mountain or Blue Ridge, between Harrisburg and the Potomac, one of the most highly diversified and perfectly preserved areas of pre-Cambrian volcanic rocks in the world. Its position is established as below the Olenellus sandstone; it presents both acid (rhyolitic) and basic (basaltic) types; it exhibits within limited shear-zones the plainest effects of dynamic action, but its great mass is nevertheless so little changed that each microscopic structure of glassy rocks is clearly recognizable. Skeleton crystals, minute pores and larger vesicles, protoclastic breaking of the phenocrysts, fluidal structures of every kind, trichites, spherulites, axiolites, lithophysal and perlitic parting have lost none of their original sharpness, in spite of the complete devitrification of the glassy base. Most of the rocks were probably always wholly or mostly crystalline, but some regions, like the Bigham Copper and Raccoon Creek, display the old spherulitic obsidians and pumice in a manner allowing of no doubt. The pyroclastic materials accompanying these old lavas are also finely developed—ash-beds, coarse and fine flow- and tuff-breccias, etc. The precise centers of eruption within this region have not yet been definitely located, but with what has already been published regarding these rocks and the further details which may be soon expected, no further description of them is here necessary.[2] The entire misunderstanding of these rocks by Rogers, Hunt, Lesley and Fraser, who interpreted them as altered slates and their secondary cleavage as bedding, has greatly retarded the solution

[1] PROFESSOR DANA once suggested that the Cortlandt massive rocks might have been formed by the metamorphism of "volcanic debris or cinders" (Am. Jour. of Science, 3d ser., Vol. 22, p. 112, Aug. 1881), but he subsequently admitted their intrusive character (ib. Vol. 28, p. 384, Nov. 1884). See also opinions of the present writer (ib. Vol. 36, p. 268, Oct. 1888).

[2] Am. Jour. of Science (3rd ser.) Vol. 44, December, 1892, and Vol. 46, July, 1893.

of the geology of South Mountain, and has for many years invested it with a reputation for complexity which it in no way deserves.[1]

In Maryland and Virginia the acid and basic lavas and tuffs of South Mountain are extended southward as an important element in the composition of the Blue Ridge. They have been somewhat studied by the writer in this region and have been mapped and described by Keith.[2] This author mentions two quartz-porphyry areas showing flow-structure and tuffs, the larger between Catoctin and Blue mountains in Maryland, and the smaller near Front Royal in Virginia. He says that the diabase shows many indications of being a surface flow, and that it extends along the Blue Ridge from Maryland half way across Virginia, with an average width of twenty miles.

Southern States.—Volcanic rocks are largely developed in the central portion of both the Carolinas, as may be gathered from the old reports of Emmons and Lieber. During the past summer the writer had the opportunity of examining the belt in Chatham and Orange counties, North Carolina, in company with the State Geologist, Professor J. A. Holmes. The time at command was inadequate for the thorough exploration of the volcanic belt which skirts the western edge of the Triassic sandstone, but in a drive from Sanford to Chapel Hill an abundance of the most typical ancient lavas, mostly of the acid type, was encountered. On the road from Sanford to Pittsboro purple felsites and porphyries showing spherulites and beautiful flow-structures, and accompanied by pyroclastic breccias and tuffs, were met with two miles north of Deep river and were almost continuously exposed to Rocky river. Here devitrified acid glasses with chains of spherulites and eutaxitic structure were collected, while beyond as far as Bynum on Haw river, four miles northeast of

[1] See J. P. Lesley: Summary Final Report, Penn. Geol. Survey, Vol. 1, p. 151, 1892.

[2] American Geologist, Vol. 10, pp. 366–68, December, 1892. Geologic Atlas of the U. S., Harper's Ferry Sheet (*in press*). For their distribution in Maryland see the Geological Map of the State, edited by G. H. Williams, and published in the World's Fair Book "Maryland," Baltimore, 1893.

Pittsboro, the only rocks seen were of the same general character. On the farm of Spence Taylor, Esq., in Pittsboro, a bright red porphyry with flow lines is exposed in so altered a condition that it can be easily cut into any form with a knife, though it still preserves all the details of its structure. It looks not unlike the well known pipe-stone, or Catlinite of Minnesota. Three quarters of a mile beyond Pittsboro on the Bynum road there is a considerable exposure of a basic amygdaloid. South of Hackney's Cross Roads there are other excellent exposures of the ancient rhyolites with finely developed spherulitic and flow-structures. Numerous specimens were here collected which place the character of these rocks as surface flows beyond a doubt. Another locality in the volcanic belt was visited on Morgan's Run, about two miles south of Chapel Hill. Here are to be seen admirable exposures of volcanic flows and breccias with finer tuff deposits, which have been extensively sheared into slates by dynamic agency. Toward the east and north these rocks pass under the transgression of Newark sandstone. The accompanying sketch-map (Fig. 2) shows the relations of the above mentioned localities in Chatham and Orange counties, N. C. From still another locality at the cross-road near the northern boundary of Chatham county, fifteen miles southwest of Chapel Hill, Professor Holmes informs me specimens of undoubted volcanic rocks have recently been secured ; he has also sent to me within the past month a suite of similar specimens from Pace's Bridge on Haw river, three miles above Bynum.

In his upper division of the Taconic System in North Carolina, Emmons describes numerous beds of "chert or hornstone" intercalated in the slates and sometimes forming isolated bosses, whose origin he is at a loss to account for. He says they are not metamorphic, but does not suggest for them an igneous origin.[1] The hypothesis that these rocks may also be of volcanic origin is sustained by Emmons' description of "brecciated conglomerates" associated with the chert beds, which are composed

[1] Geological Report of the Midland Counties, N. C., 1856, pp. 66–68.

of an argillaceous or chloritic base, containing angular chert fragments of all sizes up to two feet. He mentions many localities

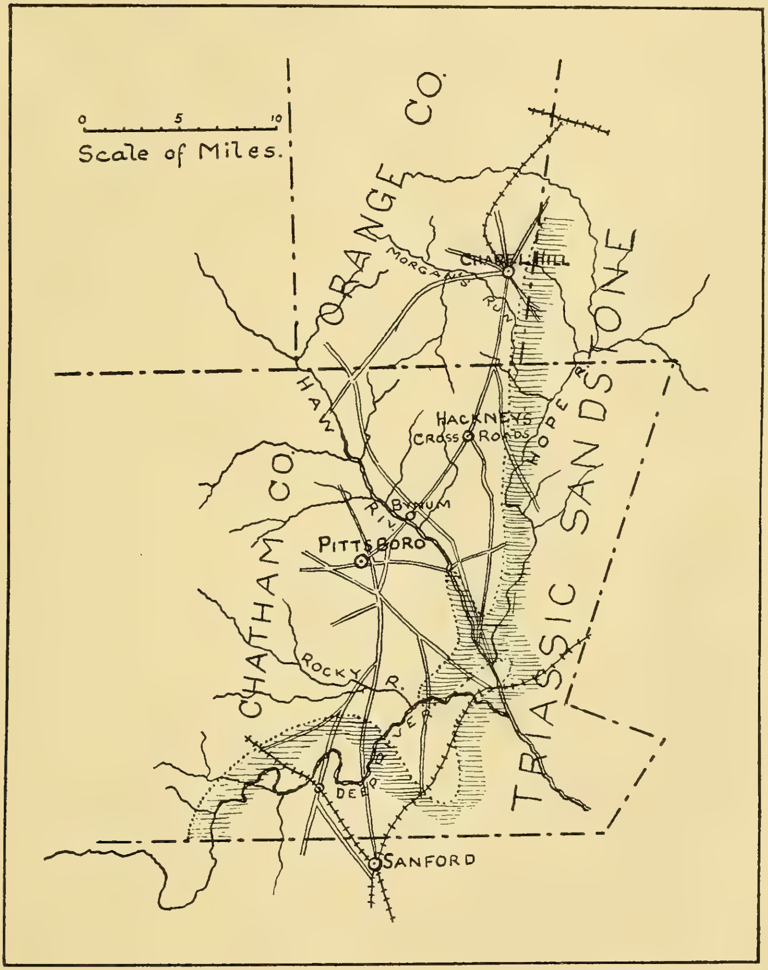


FIG. 2.

FIG. 2. Sketch map of parts of Chatham and Orange counties, N. C., showing localities for ancient volcanic rocks.

for these rocks, most of which are near the Yadkin river in Davidson, Rowan and Montgomery counties.

I am informed by Mr. Arthur Keith that he discovered a

large area of quartz-porphyry in the Great Smoky Mountains in Yancey Co., N. C., during the past summer.

The geological reports on South Carolina, by Lieber, describe a great development of igneous rocks which cross the state in the continuation of the North Carolina volcanic belt and which are themselves very probably in part of surface origin. His first report for 1856, which treats of Chesterfield, Lancaster, Chester and York counties, mentions among other more coarsely granular igneous rocks, eurite or quartz-porphyry, aphanitic-porphyry and melaphyre.[1] The counties of Union and Spartanburg, dealt with in Lieber's second report, are much poorer in igneous rocks, though he here adds the types schistose aphanite and minette. On the geological map of South Carolina, published by the Department of Agriculture in 1883, the belt of aphanitic greenstones and porphyries is shown to be continuous across the state in a southwest direction, and the statement is made that the greenstones predominate toward the north, and the porphyries toward the south, in Abbeville county.

Upon an expedition undertaken at the instigation of the writer, Prof. S. L. Powell of Newbury, S. C., found at Chester abundant eruptive rocks (granites and diorites), but none of unmistakably volcanic origin. At Lancaster, on the other hand, he found amygdaloids and felsites, showing distinct flow-structures which are certainly of igneous origin and could only have solidified at the surface.

In Georgia and Alabama nothing can be stated with certainty in regard to ancient volcanic rocks as the crystalline portions of these states have not as yet been petrographically investigated. The porphyry area of Abbeville county, S. C., is probably continued into Georgia. One single specimen of quartz-porphyry showing a beautiful micropoikilitic structure, collected in northwestern Georgia near the Tennessee line, has already been mentioned by the writer.[1] A box of specimens kindly sent

[1] Report on the Survey of South Carolina for 1856, 2d ed., Columbia, 1858, p. 31. Lieber had the German ideas regarding igneous rocks and their nomenclature. His "trachyte," "domite" and "phonolite" are probably fine grained varieties of the acid volcanic types.

to me for examination by Professor Eugene Smith of Alabama, proved to contain nothing which could be identified as ancient volcanic material.

GENERAL CONCLUSIONS.

The above rapid survey of the now known and probable areas of ancient volcanic rocks in the crystalline portion of the Appalachian system reveals the fact that this class of material is both abundant and widely distributed. From Newfoundland to Georgia it has been identified. For many areas the evidence of surface or volcanic origin is conclusive, while in many others it is as yet only probable.

The areas of these ancient volcanic rocks now known fall roughly in two parallel belts (see map); of these the eastern embraces the exposures of Newfoundland, Cape Breton, Nova Scotia, the Bay of Fundy, Coast of Maine, Boston basin and the central Carolinas; while the western belt crosses the Eastern Townships and follows the Blue Ridge through southern Pennsylvania, Maryland, Virginia, North Carolina to Georgia.

The purpose of the present communication will be accomplished if it succeeds in directing attention to this group of rocks. New areas should be added; probable areas investigated; and known areas monographed all along this old mountain range. How fruitful a field is here spread out to students of geology and petrography may be seen from the results of work in analogous regions by Harker[2] and Mügge.[3]

The identification of truly volcanic rocks in highly or partly crystalline terrains possesses far more than a petrographical significance, since by fixing what was the surface at the time of their formation, they furnish a certain datum for tracing out the sequence of later geographic changes and geological development.

GEORGE HUNTINGTON WILLIAMS.

[1] Am. Jour. of Science (3d ser.) Vol. 46, p. 47, July, 1893; and this Journal, Vol. 1, p. 179, 1893.

[2] The Bala Volcanic Series of Caernarvonshire, Sedgwick prize essay for 1888, by A. HARKER, Cambridge, 1889.

[3] Untersuchungen über die "Lenneporphyre" in Westfalen und den angrenzenden Gebieten by O. MÜGGE. Neues Jahrbuch für Min., etc., Beilage Band viii., pp. 525–721, 1893.

REVOLUTION IN THE TOPOGRAPHY OF THE PACIFIC COAST SINCE THE AURIFEROUS GRAVEL PERIOD.[1]

INTRODUCTION.

It is now generally recognized that rivers are the architects and sculptors of their own valleys. The land is everywhere shaped largely by its streams, and the forms developed are serial, beginning with the river's youth and changing in the progress of time until finally the stream attains old age, and its topographic work is completed. In their early life, when rivers have their highest grade, they wash away their beds more than their banks, and cut cañons. Their beds are a succession of gentle flows, rapids, and falls, over the softer and harder beds. When by deep cutting the fall of the stream is reduced, it tends to spread out and erode its banks, the cañons widen, and the divides become narrow and sharp, with rugged peaks showing the stream's maturity, but the work of the fluvial sculptor still continues, and the mountains are reduced to hills and the hills to knolls so low that the general aspect of the country is that of a plain. The streams are powerless to erode the land below the level of this gentle plain, which has been appropriately named by Powell the Baselevel of Erosion. Thus in a complete cycle of a river's history the cañon and the broad divide, or plateau, are features of its youth; narrow, sharp, more or less rugged divides of its maturity, and the baselevel of its old age. The cañons have then disappeared, and the land reduced by long continued erosion approximately to sea level.

The development of the baselevel begins upon the seashore

[1] Published with the permission of the Director of the United States Geological Survey. Abstract from a paper upon the same subject which will appear in the 14th Annual Report of the United States Geological Survey. Read before the Geological Society of Washington, April, 1893.

by which the level is determined, and gradually spreads inland toward the principal divides. Under similar conditions the shales and limestones wear away more rapidly than the coarser sediments and crystalline rocks, and local baselevels appear for a time determined by the harder rocks. But these are all obliterated in a general baselevel when it is completely developed. The land is so unsteady that it rarely, if ever, remains without elevation or depression long enough for the complete development of a baselevel of erosion. It commonly happens, however, that the large masses of harder rocks upon the slopes of the principal divides form independent elevations in the plain which may be more or less distinctly defined upon the softer rocks. The topography of the region is then essentially a peneplain.

It is evident that a general baselevel of erosion must have originated approximately at sea level. This is the only position in which a very extensive baselevel of erosion can originate. If we now find such a baselevel at considerable elevation above the sea, its position furnishes evidence that since the baselevel was formed the country has been uplifted in the process of mountain building.

Upon our Atlantic slope, ancient baselevels of erosion are well developed in the Piedmont region and elsewhere at considerable altitudes above the sea, as shown by Davis, McGee, Willis, Hayes, and Campbell. The ancient mountains have been swept away, and the modern mountains, at least in large part, are the result of later upheavals. Similar changes have taken place on the Pacific slope. Russell found in the St. Elias range, at an elevation of over 5,000 feet, shells of marine mollusks still living along the Pacific coast, showing that the great mountain range had been uplifted in very late geologic time. So, also, the Sierra Nevada and Coast ranges, and to some extent the Cascade range, now such prominent features of the Pacific coast, have been upheaved to their present great height, and deep cañons cut upon their slopes in the later geologic ages. At an earlier epoch the whole country was comparatively low and near sea level, or, in other words, near its baselevel of erosion. The mountain

ranges were then inconspicuous and the slopes everywhere gentle.

It is the object of this paper to trace out this ancient topography and briefly to outline the great changes by which the present features were developed. Incidentally the auriferous gravels will be considered, because they originated in large part at the beginning of its topographic revolution, which has on this account a most important economic interest.

TOPOGRAPHY OF THE PACIFIC SLOPE.

There are two prominent topographic belts on the Pacific slope. One is the platform of the interior basin region, and the other the mountain belt which lies upon the border of the continent. The latter embraces the Sierra Nevada, Cascade, and Coast ranges, as well as the Klamath Mountains in northwestern California and southwestern Oregon, where all the ranges meet. Between the ranges to the southward of the Klamath Mountains lies the Great valley of California, and to the northward the Sound valley extends from central Oregon across the state of Washington. The mountains are everywhere deeply cañoned by the rivers, but if we take a more general view, overlooking those features which are still developing, we shall discover others of much greater antiquity.

ANCIENT BASELEVEL OF EROSION.

Upon the northwestern and northern border of the Sacramento valley.—Upon the northwestern border of the Sacramento valley is a well-marked plain of erosion, which extends for nearly one hundred miles from about the 40th parallel around the northern end of the Sacramento valley to near the Great Bend of Pit river. It varies from one to fourteen miles in width, and is best marked in the Greasewood and Bald hills of Tehama and Shasta counties. The larger portion of the plain has been carved upon the upturned edges of the Cretaceous strata, and the denudation has reduced the thick, hard conglomerates and sandstones to the same level as the soft shales. At a number of places the well-defined plain extends for several miles into the area of harder

and more durable metamorphic rocks of the Klamath Mountains. Excellent views of this plain may be obtained from the Red Bluff and Hayfork stage road, five miles northwest of Hunter's postoffice, and from the mountain roads and trails leading westward from Stephenson's, Miller's, Lowrey's, and Paskenta, in Tehama county.

In the Klamath Mountains.—The plain already noted lies at the southeastern base of the Klamath Mountains, and passes by gradual and rapid transition into the steeper slopes of the mountains in such a way as to indicate that the plain may have once extended across the region now occupied by the Klamath Mountains. Within that group the plain has been recognized thirty miles southeast of Humboldt bay, about Shower's pass, at an altitude of nearly 4,000 feet, and a little farther east, in the even crest of South Fork Mountain, at an altitude of 6,000 feet. Major J. W. Powell informs me that he has observed a deformed baselevel in the Coast Range north of San Francisco. It will doubtless yet be found at many points, but on account of the great deformation which has taken place in the Klamath Mountains and Coast Range since the baselevel was formed, it is difficult to trace.

On the western slope of the Sierra Nevada.—The baselevel we have followed from Elder creek to Pit river was evidently determined by a body of water occupying the Sacramento valley, and traces of a corresponding level might be expected along the opposite shore about the Sierra Nevada.

The western slope of that range may be briefly described as an inclined plane, interrupted only by the narrow cañons of the present streams. Professor J. D. Whitney graphically portrayed the region as follows: "To one standing on some point, not too elevated, but from which a good view of the surface of the country along the flanks of the Sierra may be had, its slope will appear to be quite uniform and unbroken to one looking along a line parallel with the general trend of the range. It will seem, provided the point of view be favorably selected, as if the whole region was a gently descending plain, sloping down to the Great valley at an angle of not more than two or three degrees. And

the slope of the Sierra is—in the mining region at least—quite moderate, for if we allow a rise of 7,000 feet from the lower edge of the foothills to the crest of the range, the distance between the two points being about seventy miles, the average rise is only 100 feet to the mile, which gives an angle of slope of less than two degrees. And if one ascends the Sierra, keeping on the divide between any two rivers in the mining districts, he will find himself, for most of the time at least, on what seems to be a plain with a very gentle rise. Let the traveler, however, turn and attempt to make his way across the country, in a line parallel with the crest of the range, and he will discover that this apparent plain is cut into by the gorges or cañons in which the present rivers run, in a most extraordinary manner; he will find it several hours' work to descend into one of these and rise again to the general level on the other side, even if assisted by a well-beaten trail. All along the western slope of the Sierra the streams have worn for themselves deep cañons, and it is these tremendous gorges which form the leading feature of the topography of the region. If the streams ran nearly on a level with the general elevation of the surface, the whole character of the mountain slope would be changed. This was formerly the condition of the drainage of the Sierra slope."[1] Concerning the topography of the same region, Mr. Ross E. Browne remarks that "at certain favorably located points an extended view is obtained of the Forest Hill and neighboring divides. Upon losing the effect of the detail, one receives the impression of a general uniformity in the grades of the summit-lines. These summit-lines appear as the remaining traces of a gently undulating plain, sloping regularly from the bases of the massive peaks of the Sierra to the Sacramento valley."[2] Extended views of the western slope of the Sierra Nevada may be obtained at many points from the Central Pacific railroad between Colfax and the summit, and they fully illustrate the feature referred to.

[1] Auriferous Gravels of the Sierra Nevada of California, by J. D. WHITNEY. Pp. 63-64.

[2] The Ancient River Beds of the Forest Hill Divide. Tenth Annual Report of the State Mineralogist of California, 1890, p. 435.

This uniformity of gentle slope is enhanced in some cases, especially in the region of the American and Yuba rivers, by the broad, flat-topped lava flows which occupy the divides between the cañons. Sometimes it appears that the volcanics are thin, while at other places, according to Whitney their thickness is very large, quite often reaching 400 or 500 feet, and occasionally much exceeding that amount. The plain, however, is not limited to the areas occupied by volcanic rocks, but has a wide distribution over areas of closely folded auriferous slates, and cannot be attributed to the constructive effects of volcanic eruptions.

Mr. Gilbert was the first to call attention to the fact that this uniform surface is due to erosion upon a system of plicated strata, and "could only have been accomplished by streams flowing at a low angle,"[1] in other words, the plain must have originated essentially as a baselevel of erosion.

Judging from the topographic maps recently prepared for the geological work in the gold belt, as well as from the observations of Whitney,[2] Petty,[2] Goodyear,[2] Lindgren,[3] Turner, and myself, it appears that the inclined plateau which now forms the western slope of the Sierra Nevada was originally not worn down to so complete a plain as that already described upon the western side of the valley.

Mr. Lindgren (l. c.) says, "that the Sierra Nevada, before the accumulation of the gravels began, was a mountain range greatly worn down by erosion, but not reduced to a baselevel of erosion. It cannot even, on the whole, be regarded as a peneplain, above which isolated and more resistant hills projected. The declivities and irregularities of the old surface are too considerable for that, nor are the projecting hills invariably composed of the hardest rock-masses."

While some of the irregularities now recognized in the old plain upon the western slope of the range are due, as urged by

[1] Science, Vol. 1, p. 195, March 23, 1883.

[2] Auriferous Gravels of the Sierra Nevada of California.

[3] Two Neocene Rivers of California. Bull. Geol. Soc. of America, Vol. 4, p. 298.

Mr. Turner, to protruding hard rocks, it is possible that a considerable portion resulted from deformation when the Sierra Nevada was upheaved. For it will be shown later on that since this peneplain was formed by erosion, the Sierra Nevada has been greatly uplifted, and it would be very remarkable indeed if in the upheaval of such an enormous mass as the Sierra Nevada the original plain of its western slope were not warped and broken.

Platform of the interior region.—The fact that the baselevel plain passes to the eastward from the northern end of the Sacramento valley beneath the lavas of the Lassen Peak district, suggests that it may reach the platform of the interior region, which is now covered by volcanic material. Within northeastern California and the adjacent portion of Oregon there are vast stretches of level plains which are nearly of the same altitude above the sea. As far as known, all the surrounding hills and mountains are of lava. There are no projecting peaks of older rocks, and their absence from wide stretches of plateau country tends to show a general level of the subjacent surface analogous to that of the interior plateau in British Columbia described by Dr. G. M. Dawson.

The erosion plains we have traced upon the borders of the Sacramento valley, in the Klamath Mountains, upon the western slope of the Sierra Nevada, and probably also in the interior region of northeastern California, join one another in such a way as to show that they are simply different portions of one extensive baselevel of erosion which formerly spread over a large part, if not the whole, of middle and northern California and the adjacent portion of Oregon. What is the geological age of this plain of erosion?

DEPOSITS UPON THE BORDER OF THE ANCIENT BASELEVEL.

General statement.—In order to determine the conditions under which the baselevel was developed, and its age, it is necessary to study the formations deposited during its development. At the eastern edge of the baselevel, in the Sacramento valley, there are three formations, all of which were more or less

influenced by it in their distribution. Only two of these, the middle and the lower, need here be considered. The middle formation is a tuff which has already been called the Tuscan tuff. Below the Tuscan tuff and above the Cretaceous are gravels, sands, and clays, which apparently occupy the exact taxonomic position of the Ione formation of Becker, Lindgren,[1] and Turner, and may therefore be appropriately designated by the same name.

Tuscan tuff.—The Tuscan tuff is composed wholly of volcanic material. It will be considered first, for the reason that it can be most easily identified in different localities, and can be used to great advantage as a reference plane in considering the Ione.

On the western border of the Sacramento valley the most southern exposure yet observed is on Thomes creek, four miles east of Paskenta. From this point it has been traced with varying thickness for fifty miles across all the streams, cutting the eastern margin of the baselevel from Elder creek to Redding. It continues, with interruptions, around the northern end of the Sacramento valley to the thick deposits of similar material in the Lassen Peak region. It thins out to the westward and laps over on the baselevel in such a way as to indicate that the baselevel was formed before the great volcanic eruption which gave birth to the tuff.

Ione formation.—Beneath the Tuscan formation lies the Ione, which rests upon the upturned and eroded edges of the Cretaceous (Shasta-Chico) strata with conspicuous unconformity. In the Bald Hills region, northeast of Paskenta, it is composed of clay, and thins out rapidly to the westward against the edge of the baselevel. Farther northward the formation thickens somewhat, and contains much gravel, but everywhere it thins out rapidly to the edge of the baselevel. In the Lassen Peak region, beneath the lava, it has its greatest development, and is many hundreds of feet in thickness. To the northeastward it borders

[1] Geological Atlas of the United States. Text accompanying the Sacramento sheet.

upon the baselevel of the Klamath Mountains, while in the opposite direction it appears to stretch up to the high plateau at the northern end of the Sierra Nevada, and shows the features already noted of tapering abruptly to the edge of the baselevel plain. This formation might be considered a fringe to the baselevel, and evidently was deposited at least in part during the baselevel period.

The earlier auriferous gravels upon the slopes of the Sierra Nevada are older than the volcanic flows of the same region. They are regarded by Messrs. Turner and Lindgren and the writer as of essentially the same age as the Ione formation in the Great valley of California. The auriferous gravels were accumulated and deposited upon the flanks of the range, while the finer material, sand and clay, were carried into the Sacramento valley.

AGE OF THE BASELEVEL OF EROSION.

The age of the baselevel must be determined by reference to the formation with which it is associated. It is evidently of more recent origin than the Cretaceous, since it truncates the upturned edges of the Shasta-Chico series, and these are the youngest strata upon which it has yet been seen. It was already developed at the time the earlier auriferous gravels were deposited, for they lie in the broad shallow valleys which belong to the baselevel plain. The erosion by which it was developed therefore occupied a part or the whole of the time interval between the upheaval of the land at the close of the Chico epoch (Cretaceous) and the deposition of the auriferous gravels.

The age of the earlier auriferous gravels has not yet been fully determined, although they have been the subject of much investigation. That of the later gravels will not be considered here. Professor J. D. Whitney, in his "Auriferous Gravels of the Sierra Nevada of California," page 283, says: "It appears probable, on stratigraphical grounds, that the detrital beds overlying the bed rock of the Sierra Nevada represent the whole

Tertiary period, that is, that they have been forming since the beginning of that epoch.[1] . . . The evidence of the geological age of the gravel deposits afforded by the plants found in the sedimentary beds underlying the latest eruptive masses in the mining region of the Sierra has already been discussed by Mr. Lesquereux. He distinctly recognizes the presence in this flora of forms identical with or closely allied to those of the Miocene; but still calls the age of the group Pliocene. Something of the same kind seems to be legitimately inferred from the animal forms of the same deposits. There are certain fossils which have been found only in deep-lying gravels like those of Douglas Flat and Chili Gulch. No traces of the rhinoceros, the elotherium or the small equine animal referred with doubt by Leidy to Merychippus have ever been found in deposits which could by any possibility be proved to be more recent than the basaltic overflow. It is true that the evidence thus far collected is but fragmentary. Still, taking it for what it is worth, it may be said that the affinities of these animals found in these lower deposits would indicate a Miocene rather than a Pliocene age. There are also, it is believed, stratigraphical reasons for admitting that some at least of the deposits containing these older fossils may be proved by other than palæontological evidence to belong to an older series than those strata which, though anterior to the basalts, yet contain a fauna decidedly mere Pliocene than Miocene in character."

A collection of plants made from the older auriferous gravels upon the northern end of the Sierra Nevada was examined by Professor Lesquereux, who reported that their relation is evidently to the Miocene (U. S. Geological Survey, Eighth Annual Report, p. 419). Professor L. F. Ward, who examined the same collection, agreed that they were Miocene, most likely upper Miocene.

Recently the evidence afforded by the plant remains has been

[1] By the Geological Survey of California the Tejon was regarded as Cretaceous. Palæontology, Vol. 2, p. xiii. It is now regarded as Eocene, and in Oregon lies unconformably on the Shasta-Chico series.

ably reviewed by Professor F. H. Knowlton, who studied extensive collections from the auriferous gravels of Independence Hill, Placer county, California. He concludes that the gravels are probably upper Miocene in age.[1]

On stratigraphic grounds the auriferous gravels are regarded as contemporaneous with the Ione formation of the Sacramento valley, but here, too, as in the earlier auriferous gravels, the fossil plants and shells appear to indicate that they belong to the Miocene.

That the approximate baselevel reached its greatest development about the time the earlier auriferous gravels were deposited is indicated by the fact that they lie in the broad shallow valleys of that plain. The present tendency of the organic evidence contained in the flora of these gravels is to indicate that their deposition took place during the Miocene, most likely later Miocene. The erosion necessary to develop the baselevel out of the topography resulting from the uplift at the close of the Shasta-Chico period must have occupied a long interval of time, possibly beginning in the latter part of the Cretaceous and continuing through the Eocene and earlier portion of the Miocene, but as the plain appears to have attained its maximum extent during the Miocene, it may be referred to as the Miocene baselevel.

THE ELEVATION INDICATED BY THE FLORA OF THE AURIFEROUS GRAVELS.

The flora of the region indicated by the remains found in the earlier gravels is of special interest on account of its bearing on the topography. Numerous fossil leaves have been found in the early auriferous gravels about the northern end of the Sierra Nevada at Mountain Meadows, near the summit of Spanish Peak and elsewhere on the very crest of the Sierra, at altitudes ranging from 2,900 to 6,350 feet above the sea. These plants were studied by Professor Lesquereux, who recognized among them three kinds of figs and a large number of lauraceous plants, with other forms of similar significance. Not a single species of pine

[1] U. S. Geological Survey, Bulletin 108, page 104.

or fir, such as constitute the prevailing arboreal vegetation of that region to-day was recognized in the collections.

In answer to a question concerning the climatic conditions of that region during the Miocene, as indicated by this flora, Professor Lesquereux stated that "by the presence of a large number of Laurineæ the flora becomes related in its general characters to that of a region analogous in atmospheric circumstances to Florida." With this view Professor Lester F. Ward fully agrees, and also Mr. F. H. Knowlton, who has lately given much attention to the flora of the auriferous gravels.

Mr. Knowlton, says "Lesquereux, as already stated, argued that the presence of a large number of lauraceous plants indicated a region analogous in atmospheric circumstances to Florida. From my own studies, which embrace a much larger amount of material than Lesquereux had, I am not only prepared to accept this statement but to show that it was even stronger than he could have made it out."

Florida is a comparatively low country, rising nowhere more than a few hundred feet above the sea, and it is reasonable to infer that during the early gravel period northern California, which was then analogous in atmospheric circumstances to Florida, could not have been a region of high snow-tipped mountains as it is to-day.

It is well known that during the Miocene tropical conditions extended much farther north than now, and under such circumstances it is possible that certain forms of plants may have had considerably greater range in altitude than their relatives in California have to-day.

No doubt the Sierra Nevada existed at that time, but was a very low range, at least in the northern portion, as compared with its present altitude. Yet it was high enough to supply the alder, birch, poplar, and willows, as well as the few pine leaves lately found by Mr. Turner.[1]

The evidence afforded by the flora of the region is in complete harmony with the inference drawn from the topographic

[1] Bulletin Philosophical Society of Washington, Vol. 11, p. 391.

relations, namely, that during the Miocene the country was a series of plains and peneplains with low mountain ranges, or in other words, the country was but little above its baselevel of erosion. In no other position could such extensive plains have been formed by erosion.

GEOGRAPHY OF NORTHERN CALIFORNIA DURING THE MIOCENE.

The Ione formation being well stratified was evidently laid down in a body of water having a distribution at least as extensive as the formation itself. In the Sacramento valley, as far north as Marysville Buttes, the water of the bay was salt, as shown by the marine shells found at that point by Mr. Lindgren.[1]

Upon the borders of this bay, at Ione, where the conditions were favorable for the accumulation of the vegetable matter to form lignite, the water was regarded as fresh or brackish. Farther northward only unios have been found, and the water in which the Ione formation originated was fresh. Beyond the Lassen Peak region in northern California the water was undoubtedly fresh, but whether one large lake or a series of lakes, or a water body connected directly with that of the Sacramento valley as an estuary from the sea, is a matter of doubt.

From the Great valley the sea swept across the region of the Coast Range, perhaps near the latitude of Sacramento, and extended northward over the area of the broad belt of sandstones upon the western slope to beyond Humboldt Bay. The borders of the land must have been low and swampy to make the conditions favorable for the accumulation and preservation of vegetable matter to form coal. The Sierra Nevada and Klamath Mountains themselves were low, with gentle slopes as compared with those of the present ranges, and the streams flowed down their flanks in broad, shallow valleys instead of in deep cañons as they do now.

[1] Geologic Atlas of the United States, text accompanying the Sacramento sheet. See also U. S. Geological Survey Bulletin, No. 84, by W. H. Dall and G. D. Harris, p. 197.

DEFORMATION OF THE BASELEVEL.

It is evident that since the Miocene there have been great changes of level in northern California, for instead of the original baselevel of the erosion, we have now prominent mountain ranges, whose sides are furrowed by the deep cañons of the rejuvenated streams.

The deformation of the baselevel may be studied along two lines of evidence: (1) by tracing the present variations of altitudes in the original baselevel, which must have had a very gently sloping surface itself, and (2) by tracing the deformation of the Ione deposit which, when laid down, must have been below sea level at a lower altitude than the baselevel, because deposited in the water body upon its border. Each line of evidence should corroborate the other and render conclusions concerning the deformation more trustworthy.

It is impossible to tell from what is known at present the original inclination of the baselevel. It is evident, however, that it must have been considerably less than one degree, for at that angle streams generally erode their beds much more than their banks, and cut cañons.

Upon the western edge of the baselevel, at the foot of the Klamath Mountains in Tehama county, the altitude is nearly 2,300 feet, while upon the eastern edge it is considerably less than 1,000 feet, giving the old plain in the Greasewood hills a slope of 100 feet to the mile to the eastward. Across this plain the present streams flow in cañons 300 to 400 feet deep, and they are still cutting. The cañons in general are deepest to the westward and gradually run out to the Sacramento river in the newer deposits which fill the valley. It is evident that since the baselevel was formed, it has been affected by differential elevation in the uplifting of the Coast Range and Klamath Mountains, just north of the fortieth parallel, to the extent of over 2,000 feet, and if we may judge from the traces of the baselevel seen at Shower's pass and South Fork Mountain, the upheaval in the Klamath Mountains has been much greater. It has long been

maintained by Whitney and others that the principal upheaval of the Coast Range occurred at the close of the Miocene.

At the northern end of the valley the elevation of the base level is 800 feet. To the eastward it rises gradually to 1,300 and 1,700, and finally in the neighborhood of Round Mountain to 2,500 feet, showing elevation in the Lassen Peak and Sierra Nevada region east of the Sacramento valley.

Mr. G. K. Gilbert[1] was the first to recognize the broad plateau upon the western slope of the Sierra Nevada as a plain of erosion, and discussed the matter in such a way as to show that the height of the range has been considerably increased since the erosion plain was formed.

Professor LeConte advocated essentially the same view. He says:[2] "The rivers, by long work, had finally reached their base levels and rested. The scenery had assumed all the features of an old topography with its gentle flowing curves. At the end of the Tertiary came the great lava streams running down the river channels and displacing the rivers; the heaving up of the Sierra crust block on its eastern side, forming the great fault-cliff there, and transferring the crest to the extreme eastern margin; the great increase of the western slope and the consequent rejuvenescence of the vital energy of the rivers; the consequent down-cutting of these to form the present deep cañons and the resulting wild, almost savage, scenery of these mountains."

The observations of Mr. W. Lingdren[3] in the region of the Yuba and American rivers upon the western slope of the Sierra Nevada, "appear to prove that the grades of the remaining Neocene gravel channels are to a certain extent determined by the directions in which they flowed, in such way as to strongly suggest that the slope of the Sierra Nevada has been considerably increased since the time when the Neocene ante-volcanic rivers flowed over its surface. It finally appears probable, from a study of the grade curves of the remaining channels, that the

[1] Science, Vol. 1, March 23, 1883, pp. 194–195.

[2] Bull. Geol. Soc. of Am., Vol. 2, pp. 327, 328.

[3] Bulletin of the Geological Society of America, Vol. 4, p. 298.

surface of the Sierra Nevada has been deformed during this uplift, and that the most noticeable deformation has been caused by a subsidence of the portion adjoining the Great valley relatively to the middle part of the range."

Strong evidence of the deformation is furnished by the distribution of the Ione formation. As already shown, this formation was deposited about sea level. On Little Cow creek it now occurs at an altitude of 3,400 feet, and on Bear creek about 4,000 feet above the sea, indicating conclusively that since the base-level period the Lassen Peak region has been elevated at least 4,000 feet. There are indications that the elevation was still greater to the southward about the northern end of the Sierra Nevada, for between Mountain Meadows and Diamond Peak opposite Susanville the auriferous gravels supposed to belong to the estuarine Ione formation rise from 5,000 to 7,000 feet. These high gravels upon the northeastern block of the Sierra Nevada have been displaced in a remarkable manner by the upheaval of the range. The area occupied by them is about 10 × 16 miles in extent. Although the gravels cover the larger part of this area and are connected throughout, they do not appear over the whole of it. There were a few small islands of older rocks during at least the later portion of the gravel period, and at some other places within the area the gravels have either been washed away or covered up by later volcanic flows.

During the later part of the gravel period in that region, after the effusion of the andesitic lavas, more or less well defined beaches were formed around a series of volcanic islands upon what is now the very crest of the range from Fredonia Pass northeast of Mountain Meadows to Diamond Mountain. When developed, these beaches must have been at the same level in a body of standing water, but now they gradually rise to the southward from about 5,000 feet near the northern end of Mountain Meadows to 7,000 feet opposite Diamond Peak, and it is evident not only that the northern end of the range has been elevated but that the amount of elevation increased to the southward. The general inclination of this body of gravels toward Lassen

Peak, beneath whose lavas it disappears, makes it very probable indeed that they are connected with the Ione formation that disappears under the opposite edge of the same lavas bordering upon the eastern side of the Sacramento valley. If this could be definitely established it would show that the northern end of the Sierra Nevada has been elevated 7,000 feet since the gravel period of that region. It is possible that the increased elevation does not extend far to the southward, for beyond the 40th parallel the eastern crest of the range retreats to the escarpment of the main block of which the Sierra Nevada is composed.

In connection with the upheaval of the northeastern portion of the range a fault was formed along the eastern base at least beyond Honey Lake. A short distance above Janesville the gravels are displaced by a fault in which the throw is about 3,000 feet. On the very crest of the range, seven miles northwest of Janesville, the gravel rises to 7,400 feet, while at the foot of the steep slope which it caps the same gravel occurs in Mr. Weisenberger's mine at an elevation of about 4,300 feet. To the northwestward the fault runs out apparently in a monoclinal arch, later than the volcanic eruptions on the crest of the range at that point,[1] but before the final eruptions of the Lassen Peak region were completed. Mr. Lingdren has shown[2] that further south the eastern slope of the range was formed before the eruption of the andesitic lavas. There is some evidence of a similar character in the Honey Lake Region.

ORIGIN OF THE EARLIER AURIFEROUS GRAVELS.

The Tejon epoch appears to have been brought to a close, and the Niocene initiated, in northern California, without any marked change of level, unless a general subsidence,[3] so that the influences in operation during the Tejon continued into the Miocene. The old streams still carried on their enfeebled erosion, and in some places the land was completely reduced to

[1] See also Eighth Annual Report U. S. Geological Survey, p. 429.

[2] Bull. Geol. Society of America, Vol. 4, pp. 257–298.

[3] Dall and Harris: U. S. Geol. Survey, Bull. 84, p. 278.

baselevel. The removal of material was chiefly by solution, and the insoluble residuary material thus set free by the disintegration of the rocks accumulated to considerable depths upon the land.

The long period during which the land of northern California remained comparatively stationary, and which enabled the streams in many parts of that region to practically complete their cycles of erosion from youth to old age, was brought to a close by the initiation of an orogenic movement which generally increased the grade of the streams upon the western slope of the Sierra Nevada. At first the differential change of level was very moderate and increased the declivity of the streams but little, but being long continued it became in time revolutionary in its effects, and finally, accompanied by extensive volcanic eruptions, gave birth to the High Sierra of to-day with the deep cañons upon its western slope.

The first result of this change of slope was to rejuvenate the streams and invigorate erosion. On account of surface deformation which must have accompanied the upheaval of such a large mass as the Sierra, the stream grades would be differently affected even along the same channel, and in fact, as Mr. Lindgren has pointed out, in at least one case, owing to direction of flow, the stream grade has been not only diminished but reversed.[1]

The country being covered by a thick coating of soft residuary material, of which the great mass was fine particles, erosion was easy. There were coarser fragments of quartz, largely vein matter, as well as boulders of disintegration which had withstood the chemical changes. The streams readily became loaded not only to their full capacity but overloaded with the mass of fine material, and were thus forced to deposit the coarser particles. The grains and fragments not quite suspendable under the conditions of load were rolled along the bottom and rounded by attrition.

In this way the old channels of the baselevel period became filled with gravel of which by far the larger part is quartz. In

[1] Bul. Geol. Soc. of Am., Vol. 4, p. 281.

the same way the gold, being heavy, and associated with the quartz originally, accumulated in the same channels, while the fine light detritus was carried directly to the Sacramento valley.

In his paper on the ancient river beds of the Forest Hill divide,[1] Mr. Ross E. Browne classifies the auriferous gravel channel systems into three periods. The first period was prior to the first important flow of volcanic cement, the second was contemporaneous with the series of volcanic cement flows, and the third following immediately after the last important flow of volcanic cement extends to the present time. He has called attention to the predominance of quartz gravel[2] and sand in the ancient channels of the first period, and remarks that "quartz is the only important material contained in the belts (of slates) which is hard and permanent enough to resist the destructive action of the current." This is especially true when the auriferous slates are disintegrated. It is possible therefore that the predominance of quartz in the earlier gravels may indicate an earlier period in which the slopes had less declivity and disintegration exceeded transportation.[3] The fact that in the Light's cañon region of Plumas county the gravel is underlain by a sheet of residuary material which was formed before the deposition of the gravel is evidence in the same direction. Furthermore, the sand deposited with the gravel is rough, angular and unassorted, such as is derived from residuary material near at hand, and records a period of gentler declivity during the next earlier epoch.

The old channels of auriferous gravel of the first period are in a measure characterized by the large size of the deposits. Ross E. Browne states:[4] "In a general way it may be said that the channels of the second period differ from those of the first as

[1] Tenth Annual Report, State Mineralogist of California, 1890, pp. 437-439.

[2] See also J. D. WHITNEY'S Auriferous Gravels of the Sierra Nevada, page 323, who says "that in some localities the gravel is almost entirely made up of quartz boulders and pebbles."

[3] Mr. BAILEY WILLIS some time ago, in his study of the Appalachian region, came to a similar conclusion, yet unpublished, to account for the predominance of quartz pebbles in the conglomerate at the base of the Coal Measures.

[4] Tenth Annual Report State Mineralogist of California, pp. 439–441.

follows: their beds are narrower, rims steeper, and accumulations of bed rock gravel incomparably smaller." In these large accumulations of older gravels Prof. Whitney saw evidence of larger streams and heavier precipitation during the gravel period than now belongs to that region,[1] but, as pointed out by Mr. Gilbert,[2] deposition in stream channels is indicative of diminished instead of increased rainfall.

Professor Le Conte regarded the gravels as "deposits made by the turbulent action of very swift, shifting, overloaded currents" supplied with both water and debris "by the rapid melting of extensive fields of ice and snow" which were then supposed to occupy the higher portion of the range.[3]

A very important contribution to the literature of the auriferous gravels has been made lately by Mr. W. Lindgren, whose views are expressed in the following quotation:[4]

"From the rugged country in the region of their sources the rivers pursued their course down in broad valleys separated by ridges which even in the lowest foot-hills sometimes reached an elevation of a thousand feet above the channels. The outlines of the ridges were usually comparatively gentle and flowing; still, slopes of ten degrees from the channel to the summit were common and slopes as high as fifteen degrees occurred in the eastern part of the Sierra. The character of a region of old and continued erosion, commencing probably far back in the Cretaceous period, is everywhere plainly evident. In the center of the deep depressions is quite frequently found a deeper cut or "gutter," indicating a short period of more active erosive power just before the beginning of the gravel period. At this time, probably about the beginning of the Miocene period, the streams became charged with more detritus than they could carry and began to deposit their load along their lower courses, especially at places favorably situated, as, for instance, along the longitudinal valley of the South Yuba. Toward the close of the Neocene, gravels had accumulated all along the rivers up to a (present) elevation of about 5,000 or 6,000 feet; above this it is plain that erosion still continued in places with great activity and furnished some of the material deposited in the lower parts of the streams. The coarse character of much of the gravel and

[1] Climatic Changes in later Geological Times, p. 1. See also Auriferous Gravels, p. 335.

[2] Science, Vol. I., p. 194, March 23, 1883.

[3] Am. Jour. Sci., Vol. XIX., 1880, p. 184.

[4] Bul. Geol. Soc. of Am., Vol. 4, pp. 265–6.

the often remarkable absence of fine sediments in the beds point clearly to a somewhat rapid stream capable of carrying off a great deal of silt, and the accumulations are probably due to rapid overloading rather than to low grades of the rivers. The deep channels were filled and the gravels encroached on the adjoining slopes, where they were deposited in broad benches. A maximum thickness of 500 feet of deposits was attained on the South Yuba, and of from 50 to 200 feet in the other parts of the lower rivers. In the lower and middle Sierra some of the rivers then meandered over flood-plains two or three miles wide, above which the divides of bed-rock rise to a height of several hundred feet. In some instances low passes over divides were covered, and temporary bifurcation and diversion of rivers into adjoining watersheds occurred."

It is evident from the facts already known that at the time the early gravels were deposited the northern end of the Sierra Nevada was not less than 4,000 feet lower than at the present time, and that its climatic circumstances as indicated by its flora were not such as to give rise to either glaciers or extensive fields of snow.[1] For this reason it is necessary to appeal to some other cause than glaciers as the source of the great mass of debris deposited in the old auriferous gravel channels, and in view of the facts herein cited, the writer suggests that a source may be found in the large mass of residuary material upon the surface at the beginning of the gravel period. There is evidence, as already shown, that at the close of the Tejon disintegration exceeded transportation, and residuary deposits accumulated upon the gentle slopes of the land to considerable depths. This condition appears to have continued during the early Miocene. The depth of disintegrated rock would vary greatly with different formations. Upon the diorite and other rocks containing minerals subject to ready alteration it would be deepest, and their surfaces, at least in the case of the diorite, would be strewn as to-day with large and small boulders of disintegration. The quartz veins which intersect these rocks and the silicious slates would be but little affected. The gold not enclosed in quartz veins[2] would be set free.

[1] See also WHITNEY'S Auriferous Gravels, p. 295.

[2] WHITNEY'S Auriferous Gravels, p. 352.

If, when thus mantled with residuary material, the Sierra Nevada region were affected by a change of level in such a way as to slightly increase the fall of the streams upon its slopes, it is believed, as already suggested, that during a comparatively brief period owing to overloading they would be forced to deposit and fill their channels. A portion of the process is, in a measure, illustrated by what has taken place along some of the present streams of the Sierra Nevada where hydraulic mining has been extensively carried on. The streams are overloaded by the debris forced into them from the mines and their channels are at least temporarily filled with gravel.

After the deposition of the earlier gravels the declivity of some of the streams at certain points appears to have been so decreased that they deposited finer material and covered the gravel with sand and clay. This may have resulted from differential elevation, differential subsidence, or both, and there is evidence that both occurred within the gravel period. At Cherokee Flat upon the eastern border of the Sacramento valley the finer, essentially estuarine deposits, over 300 feet in thickness, lap over to the eastward upon the ancient river and shore gravels mined at that place. This overlapping evidently resulted from a subsidence of that region.

SUMMARY.

A study of the ancient topographic features upon the borders of the Sacramento valley, in the Klamath Mountains, and upon the western slope of the Sierra Nevada, shows that during the earlier portion of the auriferous gravel period, southern California, by long continued degradation, was finally reduced approximately to baselevel conditions. The mountain ranges were low, and the scenery was everywhere characterized by gently flowing slopes.

The distribution of the Ione formation and the early auriferous gravels, as well as the plant remains which they contain, point clearly to the same conclusion.

The topographic revolution consisted in developing out of such conditions the conspicuous mountain ranges of to-day.

The northern end of the Sierra Nevada has since been raised at least 4,000 feet, and possibly as much as 7,000 feet, and a fault of over 3,000 feet developed along the eastern face of that portion of the range. The Klamath Mountains may in some portions have experienced at the same time an equal upheaval. From all sides the amount of uplift decreased rapidly toward the Sacramento valley.

In the initial part of this revolution the earlier quartzose auriferous gravels were formed. The source of their material was found in the thick deposits of residuary detritus which had accumulated upon the surface of the land during the baselevel period. This large accumulation of disintegrated rock substance rendered the loading of the streams so easy that when rejuvenated by orogenic movements they became overloaded and filled their ancient channels with auriferous gravels.[1]

J. S. Diller.

U. S. Geological Survey, Washington, D. C.
December 12, 1893.

[1] Since this paper was written a very important one has been published by Prof. A. C. Lawson, on the Post-Pliocene Diastrophism of the Coast of Southern Calfornia. University of California, Bulletin of the Department of Geology, Vol. I., No. 4, pp. 115-160.

THE NAME "NEWARK" IN AMERICAN STRATIGRAPHY:

A JOINT DISCUSSION.

I.

Much time and ink have been wasted in discussing the claims of alternative stratigraphic names. In many instances controversies arise over questions of fact, but there are also numerous cases in which the facts are well understood, and individuals disagree only as to the bearing of the facts on the questions of nomenclature. Opinions differ so widely as to the principles which should determine the selection of names that facts which some regard as conclusive appear to others not at all pertinent. The road to ultimate peace lies through a war of principles; and the valuable controversy is one in which the fundamental postulates of the contestants are exposed. Holding this view of the general question, I would be understood as joining in the discussion of the term "Newark" only because a principle of stratigraphic nomenclature appears to be involved.

In a recent article B. S. Lyman says:

> "For those rocks have, from their conformability throughout, and their predominant color, and a comparative lack of fossils through a great part of them, been commonly lumped together as only a single group, formation, or system, under the general name of New Red, or Triassic, or Jurassico-Triassic, or Rhætic. Nearly forty years ago, with the bold assurance born of ignorance, perhaps quite pardonable at that time, the special name of Newark group was proposed for the whole lot, from one of its most striking local economic features, though otherwise an extremely subordinate one, and even economically perhaps inferior to the Richmond coal; and latterly there has been an effort to revive the name, long after it had fallen into well-merited oblivion."[1]

I am one of those who have seconded Russell's proposal to revive the name "Newark,"[2] and despite the brief argument

[1] Proc. Am. Phil. Soc., Vol. 31, p. 314.

[2] Am. Geol., Vol. 3, 1889, pp. 178–187.

which accompanies Lyman's protest, I am at present of opinion that the needs of geologists are better served by Newark than by New Red, Jurassic, Jurassico-Triassic, or Rhætic.

It may be assumed that there is no difference of opinion as to the propriety of giving local geographic names to the minor stratigraphic units. Such is the modern practice of most geological surveys, and it has the sanction of the International Congress of Geologists. Lyman, too, in the paper cited, introduces Pottstown shales, Lansdale shales, Norristown shales, Perkasie shales and Gwynedd shales as the names of newly recognized formations in eastern Pennsylvania and the contiguous parts of New Jersey, deriving the distinctive word in each case from the local geography. The stratigraphic units thus distinguished are all parts of the larger unit to which Redfield applied the local geographic name "Newark."

But Lyman protests against the use of the local name for the larger unit. It is not entirely clear to me whether he holds that the larger unit should have no name, or that it should not have a local name, or only that it should not receive the particular local name; and I therefore find it easier to state the basis of my own opinion than to discuss his view.

1. In my opinion *the larger unit should have an individual name.*—In the nomenclature of stratigraphy, as in language generally, it is advantageous to avoid paraphrases by giving a short name to every concept which needs frequently to be expressed. That for which Redfield proposed the name "Newark group"[1] is a stratigraphic integer, so definitely limited in nature that its individuality has been recognized in the literature of a half century. In the paper just referred to it is distinctly recognized by Lyman, who calls it in one place "the older Mesozoic rocks of New Jersey," and elsewhere "the older Mesozoic," "the so-called New Red," "the New Red beds," "the New Red." Each of these terms is used as a name rather than as a description; even the long phrase "the older Mesozoic rocks of New Jersey" is not a definition, for it is made to cover rocks, for example, the

[1] Am. Jour. Sci., 2nd ser., Vol. 22, 1856, p. 357.

Richmond coal, which are not in New Jersey. The unit is peculiarly definite in that its lower and upper limits are marked by conspicuous unconformities, while its strata are everywhere conformable with one another. Its composition, though not uniform, is so little varied that attempts to unravel its stratigraphy and structure have been successful in but few districts.

2. *The name should include a local geographic term.*—In the nomenclature of historic geology there are two parallel sets of terms, the one representing larger or smaller bodies of strata, the other representing larger or smaller divisions of geologic time. As the divisions of geologic time are based upon the classification of strata, their names have been mostly derived from stratigraphy, and there are many circumstances under which it is a matter of indifference whether a given term be construed in its stratigraphic or in its chronologic sense. Partly in this way there has arisen a widely prevalent habit of confusing strata and time. This confusion has an unfortunate influence on the treatment of problems of correlation, as it leads to language implying that the stratigraphic units of distant lands, for example, Europe and America, are the same. As I understand the case each portion of the general geologic time scale was based upon the stratigraphy of some district, usually in Europe. Correlation at a distance, for example, in America, does not determine the existence in America of the European formations, but only the existence of local formations deposited (in whole or part) in the same portions of geologic time. Or, in other words, correlation arranges the formations of a country in accordance with a standard time scale.

When the time relations of a formation or other stratigraphic unit are unknown or are imperfectly known, a name derived from the time scale can be employed only provisionally. As knowledge of fauna and flora increases, opinions change as to time relations, and experience shows that at any stage in the accumulation of paleontologic data conflicting opinions may be held by different students. Time names are thus unstable; but a geographic name, depending as it does on simple relations readily

ascertained, is permanent. The rocks in question well illustrate the confusing synonomy which arises from the employment of time names. They have been called at various times and by various writers: Silurian, Old Red, Carboniferous, Lower Carboniferous, Permian, Upper Permian, Mesozoic, Older Mesozoic, Secondary, Middle Secondary, New Red, Trias, Jura-Trias (and synonyms), Keuper, Upper Trias, Rhætic, Lias, Inferior Oolite, and Oolite.

When the chronological relations of a stratigraphic unit have been established, it becomes proper to apply to it the title of any time division including its period of formation; but the need for a local stratigraphic name, or, in other words, an individual name, does not cease. The place of the Hamilton group in the time scale is so well known that it is properly called Devonian and Paleozoic, but the local name Hamilton is still useful.

In the conceivable case of a formation or group representing the whole of a division of the time scale and no more, there might be a question of the need of a local name. But the existence of such a case has not been demonstrated, and it must be admitted that in the great majority of instances the local stratigraphic units are incommensurate with the standard time units. The body of rocks under consideration is imperfectly supplied with fossils, and little is known of the relations of its fossiliferous horizons to one another and to the upper and lower limits of the series. No one asserts that its period of formation was coëxtensive with any of the time divisions whose names have been provisionally applied to it. Opinions as to the interpretation to be given to its fossils are still divergent, and the only name which can be conveniently used by all is one which avoids the question of correlation. A local geographic name meets this requirement.

There are valid objections to a paleontologic or a purely petrographic name, but as such have not been proposed the objections need not be stated.

3. *The proper geographic term is Newark.*—Prominent among the qualifications of a geographic term for employment in strati-

graphy are (1) definite association of the geographic feature with the terrane, (2) freedom of the term from preoccupation in stratigraphy, (3) priority. The rule of definite association is satisfied if the geographic feature, being a town or district, is wholly or partly underlain by the terrane, or if, being a stream, it crosses the terrane. Preferably the portion of the terrane thus associated should be petrographically and paleontologically characteristic, but this consideration yields to priority.

The "Newark" rocks underlie the City of Newark, exhibiting typical phases of sandstone and shale and containing some fossils. The only other rocks present are of widely different character, being Pleistocene. The name Newark has been applied to no other terrane. It is the earliest geographic name proposed for this terrane.[1]

G. K. GILBERT.

II.

MR. GILBERT has very kindly invited me to answer his argument: (1) that the so-called Newark system ought to have a name, because it is a stratigraphic integer, or unit; (2) that a stratigraphic name ought to include a local geographical term; and (3) that the name Newark is the proper one, because of (a) the definite association of that geographical feature with the rock beds in question, (b) the freedom of the term from preoccupation in stratigraphy, and (c) its priority.

1. He considers that the stratigraphic unit is peculiarly definite from the conspicuous unconformities at top and bottom, while internally it is conformable throughout with little varied composition.

In eastern Pennsylvania, where the rock beds have been studied with some small approach to thoroughness, the composition is found sufficiently varied to justify at least five very conspicuously marked subdivisions of several thousand feet each. Almost all the fossils hitherto used for inferring the age of the

[1] See American Geologist: Russell, Vol. 3, p. 181, and Vol. 7, pp. 238–241; Hitchcock, Vol. 5, p. 201.

beds appear to have come from a single one of those subdivisions, one quite above the rocks of Newark, and the same that contains the Richmond coal. That coal, Gilbert says, does not occur in New Jersey, meaning, perhaps, not in large deposits like the Virginian; but yet no doubt it occurs there in thin layers and traces, just as in Pennsylvania, since the same subdivision of rock beds does extend into New Jersey. It is, perhaps, uncertain whether the Newark rocks, with their two reported fossil species, belong even to the Mesozoic.

There is in eastern Pennsylvania and New Jersey great unconformity at the top and bottom of the rocks in question; but it is not yet so certain that beds of the same age as the lowest of them do not occur conformable to Paleozoic beds in western Pennsylvania and elsewhere in eastern America, to say nothing of the West.

Clearly no claim for unity in the supposed group could be based on geographical continuity.

Would it not, indeed, be still more reasonable if he maintained that the Paleozoic rocks of the Appalachian region were a stratigraphic integer or unit, and consequently deserved a separate name?

2. There are, in truth, strong arguments in favor of generally giving local geographical names to stratigraphical groups, whether large or small. Yet there are many names of a different character that have had merit enough to become universally accepted, such as Paleozoic, Mesozoic, the Old and New Red Sandstones, Trias, Oolite, Calciferous, Corniferous, Saliferous, Carboniferous, Coal Measures, Millstone grit, Cretaceous chalk, Eocene and the like. Of course, the larger the group, the less easy to find a suitable, well-characterizing local name, the name of a place or region where the beds have been particularly studied, or much seen of men, or, as a whole, finely displayed; and that would be a difficulty with so extensive a set of beds as the one in question.

3. Gilbert, while insisting that Newark is the proper term in the present case, evidently admits that some such geographical

names are more suitable than others, requiring at least definite association with the rock beds, freedom from preoccupation, and priority.

The definite association he requires seems to be very slight; namely, the occurrence at Newark of perhaps one-tenth or one-twentieth of the beds to be included in the name, and with only two determined fossil species, plants. Suppose, in rummaging among old periodicals of forty years ago, a foot-note by some Baltimore collector were found, suggesting, without any attempt at either stratigraphic or geographical delimitation, that the whole body of Appalachian Paleozoic rocks be called the Cockeysville group, because, forsooth, the Paleozoic marble quarries there supply the city with fine building material; would not the argument for the revival of the name be quite as strong as in the almost precisely parallel case of Newark?

As to priority, and even preoccupation, and suitableness, too, is it not with geologists the same as with everybody else, that words, after all, are only used for the sake of being understood, and those words are to be used that will be most readily understood, so that currency, usage, is really the main criterion?

—Usus
Quem penes arbitrium est et jus et norma loquendi.

It is a great fundamental principle, that with the lapse of thousands of years has become more and more firmly established.

The rule of priority is an excellent one for cases otherwise doubtful or indifferent; but surely we should not be sticklers for it to the extent of raking up a name like Newark, that was unsuitable in the beginning, never did find acceptance, and was long ago wholly obsolete.

BENJAMIN SMITH LYMAN.

PHILADELPHIA, December 11, 1893.

AN ABANDONED PLEISTOCENE RIVER CHANNEL IN EASTERN INDIANA.

RUSH and Decatur counties in southeastern Indiana are at present drained by Flat Rock creek and Clifty creek. The former has its source in Henry and the latter in Decatur county. Both flow in the same general southwesterly direction, and occupy deep channels which they have eroded in the hard and homogeneous limestone of the Niagara age. They discharge their waters into the east fork of the White river, the Flat Rock above the City of Columbus and the Clifty below. During one of the later stages of the Pleistocene period, and perhaps extending into the recent period, these counties were drained by a stream whose channel had a width of forty rods and a depth of ten or twelve feet, as shown by its well-marked banks composed of coarse river gravel. The elevation of the upper part of this stream was thirty feet above that of the rock bed of the recent streams. It had a more southerly course than these, having its point of departure from the present Flat Rock creek near Rushville, and its point of union with the present Clifty creek near Milford. As indicated by the map, the river may be described in four sections.

I. From a point about three miles above Moscow P.O., the old channel, called in this region "Hurricane," may be traced in a southerly course midway between the Flat Rock creek and the Little Flat Rock creek until it encounters the latter near the county line where the latter's course is westerly. Throughout this stretch the old channel has an elevation considerably higher than the modern streams. Comparatively little water now runs through this channel except in flood time.

II. From the point where the old channel encounters the present Little Flat Rock creek to a point about a mile below

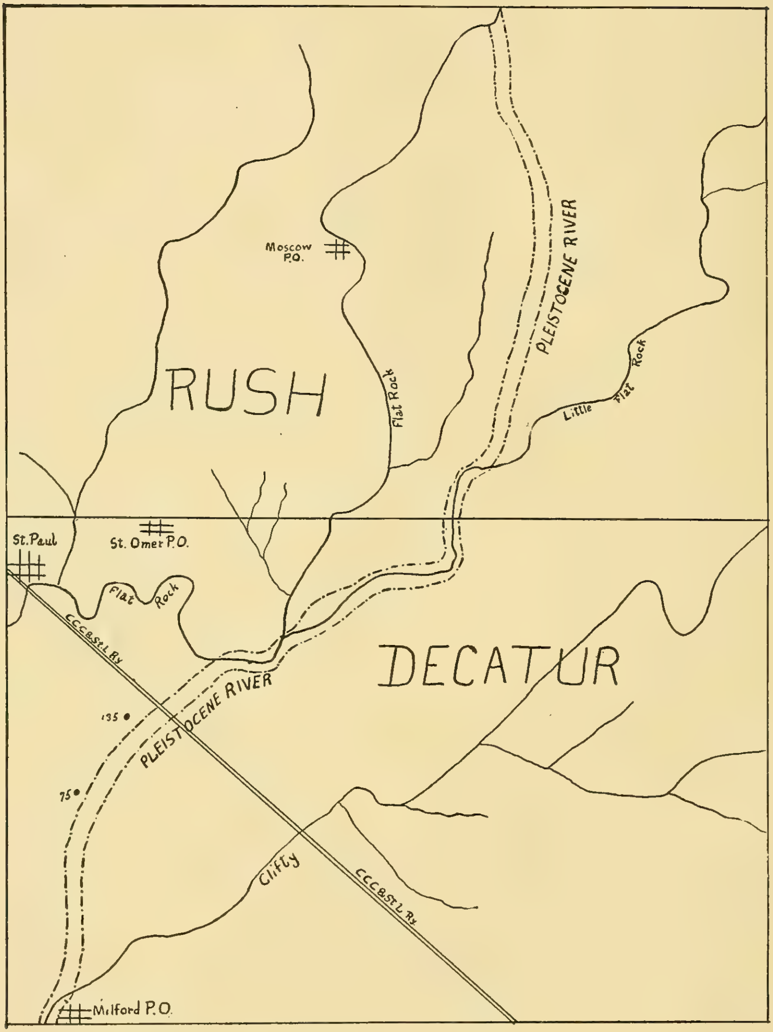
the junction of the Little Flat Rock creek with the Flat Rock creek, the old and the new channels approximately coincide. The old channel has been modified and lowered to about the level of that of the present streams.

III. The old channel departs from the recent channel at the point last described, and may be traced a little west of south to Milford P.O. It is about thirty feet above the recent channel of the Flat Rock creek at the point of departure, and has but a slight fall. The Flat Rock creek, in cutting its channel toward the north from the point where it left this ancient river, has carried away its water supply, leaving the abandoned part of the old river a relatively high marshy region known to the early settlers as "Beaver Pond." Recently an open ditch has been cut through it converting it into fertile corn and wheat land.

IV. From Milford the present Clifty creek flows through the old channel and has modified it, as in the case of the Little Flat Rock creek above mentioned.

If the Flat Rock and the Little Flat Rock creeks existed contemporaneously with the old stream they, as well as Clifty creek, were tributaries to it at the points named as their confluence, and doubtless flowed at the same relative level and had a less rapid fall than now. The evidence collected in regard to the bed of the old stream shows that it ran over the Niagara limestone in the upper part of its course with the exception of the region between the Flat Rock creek and Clifty creek (Section III.), where it flowed over Pleistocene deposits of considerable depth as shown by well sections. One of these, just below the C. C. C. & St. L. Ry. (see map), penetrated sand, clay, and bowlder clay to a depth of 135 feet without reaching rock. Another, a short distance below, is seventy-five feet deep in similar deposits without reaching their bottom.

The facts so far observed do not show precisely when the stream originated nor exactly how long it continued before its waters were diverted into their present courses. It seems probable, however, that it originated immediately after the retreat of the ice from the region, and was a part of the first definite system



Pleistocene River in Eastern Indiana — Beachler.

Scale — one mile

of drainage that developed after the ice melted away. This would make it originate in the closing stages of the Pleistocene period. From the fact that the present Flat Rock has cut its channel in limestone about sixty feet at St. Paul below the bottom of the old channel, it would appear that it had been essentially abandoned a considerable time ago. Why the Flat Rock abandoned it at Moscow, and again south of St. Omer P.O., after it had reunited with it, I am not prepared to say. Nor can I say that it may not possibly have been a subglacial channel that was abandoned as soon as the ice melted away and left its waters free to follow the lowest depression of the surface.

The existence of the old channel north of the Little Flat Rock creek was first pointed out, so far as I know, by Dr. Frank Howard, of St. Paul, Indiana, who also assisted the writer in tracing out the channel for the purpose of preparing the map.

CHARLES S. BEACHLER.

Studies for Students.

PHYSICAL GEOGRAPHY IN THE UNIVERSITY.[1]

The logical method in geography.—Success in the study of geography, as in other subjects, depends largely on the share of mental light with which the facts are illuminated. For example, during the two weeks in which my class in physical geography has recently been occupied with the tides, a long roll of tracing linen has been hanging on the laboratory wall, containing copies of a half month of tidal curves at Honolulu, Boston, Philadelphia, Port Townsend (Oregon), and Point Clear, on the Gulf of Mexico. The essential facts of tidal oscillation are thus exhibited with great clearness, thanks to the kindness of Mr. Christie, of the U. S. Coast Survey, by whom the original records were selected, and under whose direction the copies were made for me. While these curves were illuminated only by the light that came in through the laboratory windows, the facts were but imperfectly perceived. The more peculiar variations of the curves involved in the diurnal inequality of tidal amplitude and interval could not be discovered by eyesight alone, at least

[1] NOTE.—Although it was the author's intention to prepare this essay for publication as one of the "Studies for Students" of this Journal, it has been unconsciously addressed as much to teachers as to scholars. This is perhaps excusable because of the little attention generally paid to physical geography in our colleges. The chief object of the essay is to present the plan of the author's course in this subject, with the hope that it may be tried by others, and modified or extended as experience shall advise. It may be added that a selected list of our governmental maps of use in teaching has been prepared by a sub-committee of the Conference on Geography of the National Educational Association, and that its publication may be expected at an early date; that a list of grouped sheets of foreign topographical surveys, with descriptive notes, is in preparation by the author, and that a list of selected photographs and lantern slides is in contemplation. With these aids it will be easier than it now is to experiment on systematic geography in the universities. W. M. D.

not by the simple eyesight of such observers as are found among average college students. But during the same week that the class was examining these tidal tracings in the laboratory, and thereby gaining an approach to a simple inductive knowledge of the principal facts of the subject, the problem was taken up from the other side in lectures, which discussed the theoretical consequences of the interaction of two bodies, and deduced from the theory of gravitation a number of special results that ought to occur if the theory of the tides is correct. As an aid in this deductive discussion, I placed three great circles of paper around a globe, so as to represent the theoretical arrangement of the tidal equator, and high tide circle and the low tide circle, and their relations to the latitude circles of the earth. Now, returning to the tidal diagrams with the results of the tidal theory in mind, it is only the poorly trained, the dull, or the stolid "student" who feels no mental satisfaction in the successful meeting of the facts of observation and the consequences of theory. Facts before noted, but not understood, now gain meaning; facts before disconnected now fall into their natural relationships; facts before unnoticed are now searched for and found, and wonder is even excited that they were not seen sooner. Neither induction nor deduction alone satisfies the mind. However full the series of facts, however extended the deductions from theory, both facts and deductions are of small value while they remain unmated. Properly confronted, they pair off and each one reacts on its mate most favorably. If the facts are well observed and recorded, if the theory is justly based and logically extended to its consequences, the inductions and deductions mutually complete each other, and the mind is satisfied. The window light then seems a dull illumination of the tidal tracings compared to the light that shines on them from the understanding.

As with the tides of the ocean, so with the forms of the land. They are but half seen if examined only by daylight. They are less than half appreciated if seen without an understanding of

the generalizations by which they are correlated. The more complete the mental scheme by which an ideal system of topography forms is rationally explained, the more clearly can the physical eye perceive the actual features of the land surface; the more definitely can it record them in mental impressions. Topographical forms are so varied, and often so complicated, that the outer eye alone is no more competent to detect all their intricacies and correlations than to discover all the peculiarities of the tidal curves. It is true that with exceptionally keen powers of observation, and with unusual opportunity for deliberate examination, the unaided eye may come to see more and more of the ultimate facts; but these conditions are so rare that they need not be considered. The average eye, and the usual time allowed for observation do not suffice; they must be supplemented by the quickened insight that comes from rational understanding.

No better confirmation of this conclusion can be found than in the experience of those who have to employ engineers, untrained in geology and geography, to make topographical maps. The work that such surveyors produce is rigid, mechanical, unsympathetic, inaccurate, inexpressive. If time were allowed them to run out all their contours by actual measurement, an exact map might be produced; but neither time nor money can be devoted to so slow and expensive a method. Even the best surveys are necessarily sketched in great part; and the topographer must appreciate his subject before he can sketch it. He must have a clear insight into its expression; his outer eye must be supplemented by his inner eye. Then he can make up a valuable, even though not an expensive, map. I do not mean for a moment that he is to invent and not to observe; that he is to make a fancy picture instead of a true likeness. My point is simply that the difficulty of making a true likeness is so great that all aids towards it must be employed; and one of the chief aids to sharp outsight is clear insight. How can a clear geographical insight be gained?

An analogy with the study of the tides may still serve us. The facts of the tides are first presented in what seems like a

bewildering, even an overwhelming, variety, without suggestion of order or meaning. While these facts are studied and classified, let the system of the tides be deduced in accordance with accepted physical laws. Let the tidal theory be followed far enough to discover consequences so numerous and so intricate that they cannot be imitated by chance. Neither the inductive nor the deductive work should have precedence. They should advance together, but without confusing one with the other. When both processes are well advanced, let the facts be reëxamined in the light of the theory, and summon a critical judgment to determine how far the reports of outsight and insight agree. Success in such study requires that the facts shall have been closely observed, clearly described, and fairly generalized; the inductive results thus gained being held apart by themselves. It requires, also, that the theory shall have been logically extended to its legitimate consequences; the deductive results thus secured being stored away in a special mental compartment. Then, in due order, bring forth the corresponding members of the two classes of results, and judge of the success of the theory by the agreements thus discovered.

Let the same method be applied in the study of geography. Set an abundant array of facts before the class in the laboratory. Let the facts be examined and classified as far as possible, simply according to their apparent features and without regard to explanation. At the same time, present an outline of a deductive geographical system in the lecture room. During the advance of the two lines of work, compare their results frequently, but do not confuse them. In a few months a large array of facts may be examined, an extended deductive system may be developed, and the two may be compared in the most thorough manner. Every comparison aids further advance in both parts of the work. Both outsight and insight are cultivated. A geographical understanding, based on a proper combination of many mental faculties, is aroused and strengthened. The real study of geography is well begun. The several steps involved in this plan of work may now be traced in some detail.

Introductory illustration of facts.—It is well at the outset to present a collection of varied geographical illustrations, in order to bring prominently before the mind the great variety of the facts with which we have to deal. At the same time, a preliminary exercise is gained in the interpretation of different means of geographical representation. The following list will serve to indicate the class of materials from which selection may be made for a first week's laboratory work:

Heim's model of an Alpine torrent; Harden's model of Morrison's Cove, Penn., or a photograph of this model, or of Branner's model of Arkansas; Jackson's photograph of the deep valley of the Blackwater in the plateau of West Virginia; Hölzel's oleograph of the Hungarian plain; Becker's elaborately colored and shaded relief map of the Canton Glarus, Switzerland; a group of contoured map sheets, as the twelve that embrace the Berkshire plateau and the Connecticut valley in western Massachusetts, mounted as a wall map for better convenience in study; a hachured map, such as that of the Scotch Highlands, in a group of sheets of the British Ordnance Survey, also mounted as a wall map; a tinted relief map, as of New Jersey, from the topographical atlas of that state, etc., etc.

The need of the systematic study of geography is apparent from the difficulty that most students have in expressing the facts portrayed in these various illustrations. Words are not easily summoned to describe them. Many of the illustrations are on a much larger scale than is commonly employed in atlases, and the ordinary accounts of direction and distance usually employed in describing similar maps, are at once felt to be insufficient to express the varied reliefs here exhibited. How can the student best approach a perception and an understanding of the facts before him and at the same time gain an ability to describe them in fitting language?

Insufficience of inductive study.—The ordinary fund of geographical terms does not suffice to describe good maps and models with sufficient exactness. Further than this, a few questions from the instructor will show that many facts plainly set forth

are not seen at all. Interpretations and correlations are not even suspected. This is perfectly natural when it is remembered that most college students have never been taught to observe closely or to express themselves clearly in well chosen words. It is still more natural when it is remembered that the little knowledge of geography that they have brought from school is hardly more than a confused memory of an unsystematic, empirical text book. Whether their observation is directed to the semblance of facts in maps, views, and models, or to the actual facts of outdoor nature, observation is attempted only with the outer eye; the inner eye has never been opened. The idea that all the forms of the land are systematically developed has never been implanted in their minds. They possess no general and well tested deductive understanding of the development of land forms, no system of terrestrial morphology. The facts of observation excite no harmonious response from the corresponding members of a deductive geographical scheme.

While the study of geography remains in this incomplete and illogical condition, it is a blind study, although it is carried on chiefly through the eye. While the life of the features of the earth's surface is not perceived, geography is a dead study. The features of the land that the outer eye sees will awaken no sufficient sympathy in the understanding until the scientific imagination has deduced a whole system of geography, filled with mental pictures of all kinds of forms in all stages of development, among which the report from the outer eye may find its mate. However faithfully mere observation is carried on, the impression on the retina might as well be the record on a photographic plate, as far as appreciative insight and understanding are concerned. Let us therefore strive to complete a deductive geographical scheme, even as we strive to complete our deductive tidal scheme, until it shall at last be ready to meet not only all the actual variety of nature, but all the possible variety of nature. Only when such a scheme as this is well advanced is the student ready to appreciate the materials presented in the laboratory work. The maps and models shown in the first week

are therefore repeatedly introduced with others in the systematic advance of the course; and the student may gauge his progress by the increased meaning that these illustrations gain on every return.

Let us next consider the development of a deductive geographical scheme, by which external observation is to be supplemented and completed. Let it be understood at the outset that to exceed the variety of nature is an extended enterprise, a remote and ideal goal, towards which we strive. Let no excessive flight of theory carry us far from the earth and overcome us in mid-air. Let us carefully guard against an unwarranted wandering of the imagination by frequent conferences with the facts of observation, hoping to return, like old Antæus, strengthened for new efforts after every touch of Mother Earth.

The deductive geographical scheme.—It is the fundamental generalization of elementary geology to note that the lands are wasting away under the destructive attack of the weather. The hardest rocks decay; their waste creeps and washes down to lower and lower levels, never satisfied till it reaches the sea. However broad a plateau, however lofty a mountain range, it must, if time enough be allowed, be worn down to sea level under the weather; and the unceasing beat of the sea on its shores must reduce it still lower to a submarine platform. Since the remote beginning of geological time there has been time enough and plenty to spare to reduce all the lands to such a submarine platform; but as high lands still exist, it must be concluded that they are revived from time to time and from place to place by some forces antagonistic to those of subaërial denudation. In whatever way a new mass is offered to the wasting forces, let us call the forces that uplift it constructional forces; and the forms thus given, constructional forms. Let all the forces of wasting be called destructional forces; let the sea level surface, down to which a sufficiently long attack of the destructional forces will reduce any constructional form, be called the ultimate baselevel; and let the portion of geological time required for the accomplishment of this task be called a geo-

graphical cycle. Construction, destruction, baselevel and cycle are our primary terms. A full understanding of the destructional processes requires deliberate study of mineralogy and lithology, chemistry and structural geology; a good understanding of constructional forces and processes has not yet been gained, but a review of the advance made towards it carries the student through a wide range of geological theories, in which physics and mathematics are continually appealed to—perhaps sometimes with too great a confidence in the applicability of their conclusions concerning an ideal earth to the case of the actual earth.

If the cycle of destructive development is not interrupted, any constructional form will ultimately be reduced to a monotonous baselevel plain of denudation. This is a broad abstract statement. It is simply the first framework of the geographical scheme. It is a mere sketch in faint outline, needing all manner of finishing before its full meaning can be made out. It must be filled in by the gradual addition of details. The first step involves the recognition of the systematic sequence of topographic forms produced during the accomplishment of the destructive work. This should be considered before classifying the various kinds of constructional forms on which the destructional processes begin their tasks. Whatever constructional form exists at the beginning of the cycle, there is a certain general succession of features common to nearly all cases of geographical development. The understanding of this succession calls for the study of river systems and the general drainage of the land under their guidance; because it is so largely under the control of these processes that the destructive forces do their work.

Constructional drainage.—At the beginning of a cycle, there are relatively broad, massive forms, on which the carving of the destructive forces has made no mark. The unconcentrated drainage, or wet-weather wash, takes its way down the steepest slopes of the constructional surface, until the supplies from either side meet obliquely in the trough lines, forming constructional

streams; these unite, forming constructional drainage systems. If the trough lines are systematically arranged, as among the corrugations of mountain folds, the initial drainage system is definitely located; if the trough lines are faintly marked and lead irregularly about, as on the nearly level surface of a plateau, the drainage is essentially vague and unsystematic. If the general descent of the trough lines is here and there reversed into ascent, lakes are accumulated in the basins thus determined; and this is very common. If the descent of the trough lines is locally intensified, constructional falls or rapids are developed, but this is relatively rare.

Consequent drainage.—The constructional streams run down their troughs, carrying along the waste that is washed into them, and trenching channels beneath the initial constructional surface; or filling constructional hollows; that is, degrading or aggrading their course, as the necessities demand. As soon as they thus depart from their initial constructional arrangement, they may be called consequent streams. It is true that the constructional phase of a drainage system endures only a moment; yet it seems advisable to recognize this phase by employing a special name for it, before introducing the term, consequent, which indicates the much longer phase that next follows. At least, I am for the present experimenting on these two terms with my classes, and find them of value. As long as a stream flows on a line that is essentially the perpetuation of its original constructional course, it may be called a consequent stream; the trench that it cuts and the valley that is formed by the widening of the trench may be included under the name, consequent valley. Constructional features are encroached upon as the consequent features make their appearance. A constructional lake decreases in size by filling at the inlet and cutting down at the outlet; while thus dwindling away, it is a consequent lake. A fall or cascade recedes from its initial constructional position; but as long as it endures it is a consequent fall.

Subsequent drainage features.—As the consequent streams

deepen their valleys beneath the constructional surface, it often happens that they discover structures of unequal hardness. If, in passing down stream, a weak structure succeeds a hard structure, the valley will be quickly deepened in the former and slowly in the latter; a local increase of slope appears and a fall or cascade is the result. This is a subsequent fall on a consequent stream. It endures until the harder structure is worn down or back so far that it overtakes the deepening of the stream bed below the fall. The extinction of falls is accomplished in adolescence on large streams and on tilted rocks; but it may not be reached until maturity on the smaller streams in regions of horizontal strata.

A further consequence of the discovery of the variable resistance of internal structure is the variable rate at which the narrow young consequent valley widens into the more mature open valley. If the consequent stream crosses a local transverse belt of hard rocks, the gorge-like form of the valley walls may there be retained into the maturity of the region as a whole. If it crosses a belt of weak rocks, the consequent valley may there widen so greatly as to develop other valleys on either side of its path. Thus many a transverse consequent stream, cutting its valleys across belts of harder and softer structures, allows the development of longitudinal valleys on every belt of weak structure that it traverses, while the intermediate belts of harder structure stand up as longitudinal dividing ridges. The longitudinal streams and valleys are then called subsequent branches of the transverse consequent streams and valleys. Each of the subsequent streams deepens its valley only as fast as the down-stream deepening of the consequent valley permits.

It is extremely important to recognize the difference thus indicated between consequent and subsequent streams. The first control the drainage of a region in its early stages of development. The second are of increasing importance in the secondary and later stages of growth, when they share the drainage of the region with the surviving consequent streams. Subsequent falls

frequently appear on consequent streams, but they are rare on subsequent streams.

It is manifest that the development of subsequent streams will progress to the greatest extent in regions of disordered and complicated structure, in which the attitude of the rocks is varied, and in which contrasts of hardness are well marked. Such is the case in mountainous regions. On the other hand, regions of horizontal structure have no normal subsequent streams. All the branch streams are either perpetuated constant streams, or else they are developed under accidental controls, of which no definite account can be given. It is to these self-guided streams that McGee applies the term, autogenetic.

Divides.—The constructional divides waste slowly and become consequent divides. They are well defined in a region of distinct constructional relief; they are vague or practically absent on the even surface of young plains, where the drainage areas are really undivided. As subsequent streams develop, especially in regions of tilted structure, they frequently split a consequent divide, and make two subsequent divides between which lies the growing subsequent valley. As the subsequent divides are split further and further apart, lateral subsequent streams are developed down the internal slopes of the subsequent valley; and these are in headwater opposition to the lateral streams on the diminishing slopes of the adjacent consequent valleys. During changes thus produced in the position of divides, they migrate by slow creeping as long as the competing streams are in headwater opposition; but if, as sometimes happens, the head of an encroaching subsequent stream pushes its divide back until it cuts into the side of a consequent stream, then the divide leaps around the consequent headwaters above the point of capture, and a considerable area that had been tributary to the captured stream is suddenly transferred to the capturing stream.

A limit of these re-arrangements is gradually approached. The persistent consequent streams and the successful subsequent streams come to an understanding about their drainage areas. The divides as well as the streams are then maturely adjusted to

the structures on which they are developed; and thenceforward further change is slow.

Stream profiles.—Let us next examine the changes produced in the initial profile of the troughs where the first constructional streams settled. The irregularities of constructional profile which determine lakes and falls are in most cases soon extinguished. The profile of a consequent stream may for a time possess unequal slopes at its subsequent falls, but it soon attain- a tolerably systematic curve of descent, steeper near the head-waters, flatter near the mouth. While the young stream has abundant fall and rapid current, with moderate load delivered from the relatively simple constructional and consequent slopes of its basin, it deepens its trench rapidly. But as the profile becomes flatter and the current runs slower, and as the area of wasting slopes increases by the deepening of the consequent valleys and the development of subsequent valleys, a time will soon arrive when the carrying power is reduced to equality with the load; and from this time on the deepening of the valley is very much slower than before. It is only as the load from the wasting slopes decreases in amount that the deepening can go on. Following certain French writers, the profile of the stream when this balanced condition is reached has been called the *profile of equilibrium.* The term is inconveniently long; but the idea is of essential importance. Mr. Gilbert has recently suggested to me that a stream in this condition of balance between degrading and aggrading might be called a graded stream; and its slope, a graded slope.

It is sometimes said that streams in this condition have reached baselevel; but this introduces a confusion of ideas that should be avoided. For example: given two constructional areas of similar form and altitude, and under equivalent climatic conditions; but let one be made of resistant rocks, and the other of weak rocks. The baselevel is the same for both. The streams will cut deep into the harder mass, producing strong relief before reaching an equilibrium profile; because its waste is shed so slowly that the streams can carry it on a faint slope.

They can cut only shallow valleys in the weaker mass, for its waste will be shed so rapidly that a steep slope is needed by the streams to carry the waste away. The contrast between the two areas is strengthened if the region of harder structure has a plentiful rainfall, and the region of weaker structure has a light rainfall. All of these points of difference are with difficulty stated, if the streams are said to have reached baselevel when their carrying power is reduced to equality with their load.

In certain cases, it seems to be possible for a stream to cut down its profile to a gentler grade in its early adolescence than is suitable to later adolescence and maturity. If we conceive that the load offered by the waste from the valley slopes continues to increase after the grading of the stream has been reached, then the grade must be steepened again by the deposition of the excess of load ; thus increasing carrying power and decreasing load, and maintaining an equilibrium. Local examples of this relation are often seen in valleys among mountains, where a lateral stream is depositing an alluvial fan in the larger valley that it enters. The larger valley was deepened before the lateral valley had gained a considerable area of wasting slopes ; but as the lateral valley grows headwards and discharges an increasing volume of waste, it cannot all be carried by the main stream, and hence the main valley is clogged up, and its grade is somewhat increased.

Stages in the cycle of geographic development.—Following the terminology of organic growth, it is convenient to speak of the successive stages in the geographical cycle as infancy, youth, adolescence, maturity, old age, and perhaps second childhood. Let us consider particularly the activities of the drainage system as determined by the topographic form of a region in its different stages.

In infancy, the rainfall is slowly concentrated from the broad constructional surface ; it is only gradually collected into streams ; it is often delayed in lakes. Much of it is lost by evaporation, and the ratio of discharge at the river mouth to rainfall over the river basin is relatively low. The initial streams simply adopt the courses offered to them, without the least consideration or

foresight regarding the difficulties that these courses may involve in the process of valley-trenching. The load that they have to carry is relatively light; being only the waste that creeps and washes down the broad constructional slopes, under the guidance of the unconcentrated drainage.

In youth and adolescence, the drainage lines are increased in number and greatly improved in their ability to gather and discharge the rainfall quickly. Numerous little trenches are incised in the broad constructional surface, and the distance that the land waste washes and creeps under the guidance of unconcentrated drainage is much lessened; delay in lakes is decreased; the steep lateral slopes of the young consequent valleys furnish an increasing amount of load to the streams, although they still as a rule have carrying power to spare in their impetuous currents. A good beginning is made in the search for the best location of subsequent streams. As the subsequent streams are better developed in later adolesence, the original broad constructional forms are minutely carved, many subsequent divides are established, the discharge of rainfall is very prompt, and the load of waste that the streams have to carry is notably increased.

In maturity the relief retains much of the intensity of adolescence, and adds thereto a great variety of features. The valley lines are closely adjusted to the structure of the region, this condition having been gained by a delicate and thorough process of natural selection, in which the most suitable drainage lines survive, and the less suitable ones are shortened or extinguished. The impetuosity of youth has disappeared; all the larger streams have developed grades on which their ability to do work is nicely adjusted to the work that they have to do; the lower courses already show signs of age, while the upper twig-like branches are relatively youthful. The whole drainage system is earnestly at work in its task of baseleveling the region, and the forms that the region has assumed bear witness to the close search made by the streams for every available line of effective work.

From this time onward, there is a general fading away of strength and variety, both of forms and activities. The deepen-

ing of the valleys progresses even slower than the slow wasting away of the hill tops ; the relief fades ; the load offered to the streams lessens. The rainfall slowly decreases as a normal consequence of decrease of altitude ; the ratio of river discharge to rainfall decreases ; the small headwater branches shorten and dwindle away ; the close adjustment of stream to structure is more or less lost, especially by the larger rivers, which meander and wander somewhat freely over the peneplain of denudation. Extreme old age or second childhood is, like first childhood, characterized by imperfect work ; activities that were undeveloped in the earlier stage having been lost in the later stage.

All this should be so carefully imagined and so frequently reviewed that the orderly sequence of changes may pass easily before the mind. The mind should come to be in so close a sympathy with the progress of the cycle as to forget human measures of time and catch instead the rhythm of geographical development; even to the point of almost wishing to hurry to one place or another where some change of drainage or of form is imminent, for fear of failing to be in time to see it in its present stage.

Shore lines.—While the subaërial forces are denuding the surface of the land, the waves are beating on the shore and reducing the land mass to a submarine platform. They begin their work on a level line, contouring around the slope of the land mass as it is offered to them. The contour is simple if the sea lies on a rising sea bottom, evenly spread over with sedimentary deposits ; the contour is irregular if the sea lies on a depressed land, more or less roughened by previous denudation. The waves of a great ocean work rapidly on a leeward shore, especially if it has a steep slope and if its rocks are not too hard : but if the descent to deeper water is very gradual, the waves may for a time spend their force chiefly on the bottom, building off-shore bars with the material they gather up, and thus deepening the water outside of the bars for a better attack on the land later on. The shore line is generally simplified, as the attack advances, but it may for a time become more irregular if the waves are strong and the land structure is of diverse resistances. Its changes deserve as care-

ful an analysis as is given to the forms of the land; but they cannot be traced here for lack of space.

Illustrations of the deductive scheme.—However much the advance of a deductive scheme of study may be aided by reference to concrete illustrations during its progress, its statement should be abstract, in order to emphasize the essentially deductive side of the study. It is difficult to follow such a method without artificial aids. Hence, in discussing the theory of the tides, a model of certain theoretical tidal circles was introduced for the convenience of definition and argument. It was found to be an effective aid in reaching certain geometrical consequences that follow from the rotation of the earth on an axis that is not coincident with the axis of the tidal circles. This model was an illustration of the same order as the diagrams employed in text-books on geometry. In the same way, a series of some thirty rough paper reliefs, constructed several years ago to illustrate a course of lectures to teachers under the auspices of the Boston Society of Natural History, are introduced to aid in giving clearness to the conception of the geographical scheme. They are roughly made; hardly better than blackboard diagrams, except in having three dimensions; yet they certainly serve a good purpose as aids in following deductive statements. Being two or three feet in length and yet light enough to handle easily, they are frequently brought into the lecture room, although they are used chiefly in the laboratory, where they can be examined and described deliberately. Nearly all the points thus far mentioned are illustrated in one way or another by these models; but I can here give account of only a few of them.

While occupied with the first considerations of the cycle and its systematic variations of relief, both in intensity and variety, use is made of three simple models, which are found to be of particular value in fixing the fundamental ideas. The first shows a broad upland, traversed by a main river with a few branching streams, all in valleys of the canyon type. The form of the second is well diversified, there being about as much of lowland in its wide open valleys as there is of upland on its well separated

hills. The third is a broad lowland for the most part; but low hills rise above the general level near the headwaters of the streams. The main river has essentially the same course in all three models and there is a manifest relation in the position of the streams and interstream hills of the series, plainly showing genetic relationship. The three models are different forms of the same region at certain stages in its cycle of development. Exercises are held in the simple description of these forms, and of other forms that might be interpolated in the series. It is suggested that the duration of a cycle should be divided into a hundred equal parts, and that the stages occupied by the three models should be designated by appropriate numbers. After some discussion, it is agreed that they may be represented by five, twenty and forty; thus impressing the idea that maturity is reached long before middle life; and that the passage through old age is extremely slow compared to the advance from youth well into maturity. These exercises are accompanied by others in which illustrations of actual geographical forms are presented, as will be explained later; but it is important that the different character of the two should be clearly kept before the mind.

Complications of the simple scheme.—The difficulty of finding examples of actual forms in the various stages of development of a single cycle suggests that the departures from the ideal uninterrupted cycle should be examined. These are of two kinds, which I am accustomed to call accidents and interruptions. Such departures as do not involve a change in the attitude of a land mass with respect to its baselevel may be classed under the first heading as accidents; those which do involve a change with respect to baselevel will fall under the second heading of interruptions.

The most important accidents are climatic and volcanic. Climatic accidents include changes from humid to arid, and from cooler to warmer conditions, independent of the normal climatic change due to loss of relief from youth to old age. A study of such a region as the Great Salt Lake basin, or as the glaciated

district of northeastern America assures us that these accidents may succeed each other rapidly; very rapidly compared to the rate of normal climatic change dependent on loss of relief from a constructional beginning to a destructional end. Volcanic accidents include the building of cones and the outpouring of lava flows. Both the glacial and the volcanic accidents may occur at any stage of a cycle. They both in a way involve constructional processes; both may be regarded as furnishing examples of new constructional forms; but when looked at with respect to the surface on which these accidents are imposed, and with respect to the relatively brief endurance of the effects of the accidents, they are seen in their relatively subordinate character. When sheets of drift are heavily spread over a country of low relief, or when heavy lava floods cover and bury some antecedent topography, the accidents assume such proportions that they may be considered as revolutions, after which a new start is made in the processes of denudation.

A cycle is interrupted when the land mass rises or sinks, or when it is warped, twisted, or broken. Like accidents, interruptions may happen at any stage of development. It is then convenient to say that the destructional form attained in the first incomplete cycle shall be called the constructional form of the new cycle, into which the region enters, more or less tilted or deformed from its former shape. Assuming for the moment that the constructional process is so rapid that its duration may be neglected, it follows that in cases of simple vertical movement, up or down, the rivers and streams at once proceed to adapt their activities to the new conditions. They are shortened and betrunked, if the interruption is a depression; they are revived and extended if the interruption is an elevation. These two special conditions are illustrated by paper models. One model exhibits a rolling country, into which a branching bay enters; a stream descending into the head of every branch of the bay. No flats occur at the head of the bays; no cliffs are seen on the headlands. Hence it is said, that on reaching maturity this country was depressed, and that the depression occurred very recently.

The numerical expression of this example would be 20, —, 0: the minus sign not indicating subtraction, but merely signifying depression; and the zero indicating that no advance has been yet made in the new cyle. Another model exhibits a broad, gently undulating upland, traversed by a very narrow canyon. This is interpreted to signify that an elevation occurred in the old age of the region, and that since then the streams have simply entered a new youth, incising young valleys in the uplifted peneplain. The formula of this example would be 60, +, 3. Examples involving deformation of a land surface, and the accompanying possibility of antecedent streams, are more complicated, and cannot be here introduced.

It is convenient to use the term, episode, for slight interruptions, so as to express their relative unimportance. I have also attempted the use of the term, chapter, for an unfinished cycle; but in talking with students this specialization of terms hardly seems necessary. Any region whose surface has been developed, partly with relation to one baselevel, and partly in relation to another; that is, any form whose development has involved two or more incomplete cycles, is said to have a composite topography. Many examples of such forms are encountered.

Special features of second or later cycles.—It is interesting to notice that, in certain cases, the adolescent stages of a second or later cycle, following the elevation of a region well advanced in a previous cycle, present features that did not characterize its first adolescence. One case of this kind is seen in meandering river gorges. Young rivers in their first cycle may cut crooked gorges, but they then follow consequent courses, and these cannot manifest the close relation between volume and radius of curvature that is seen in true meanders. This relation is found only in oldish rivers, which develop systematic meanders on their own flood plains. But if the region on which these rivers flow is introduced into a new cycle by uniform elevation, the rivers may cut down their meandering channels and produce meandering gorges. The Osage in Mis-

souri,[1] and the north branch of the Susquehanna in Pennsylvania; the Seine in northwestern France, and the Moselle in western Germany, may be cited in illustration of this kind of occurrence.

Another case in which a second adolescence is unlike the first is found in regions of tilted structure, where the strata are of diverse resistance, thus giving good opportunity for the development of subsequent streams. In the beginning of the first cycle there are no subsequent streams. All the drainage is constructional (antecedent streams not being now considered). In adolescence, the drainage is chiefly consequent, although subsequent side streams are then beginning to bud forth from the consequent streams. In past-mature stages, the subsequent streams may have acquired a considerable part of the drainage area. Now, if a region of this kind, with consequent and subsequent drainage, is bodily elevated, all the streams are revived; they all cut down new trenches toward the new baselevel. But in this case the revived subsequent streams begin the new work at the same time as the revived consequent streams, and they will go on rapidly in acquiring still more drainage area. Therefore, in the adolescence or maturity of the second cycle, the drainage area acquired by the subsequent streams will be proportionately large; much larger than at the same stage of the first cycle. Much faith may be placed in this deduction. If the drainage of an adolescent region is largely subsequent, and but little consequent, the region may be regarded as almost certainly in a second cycle of development, after a first cycle of well-advanced age.

Illustrative material.—One of the greatest difficulties in the way of teaching physical geography arises from the failure of the student to know what the teacher is talking about. The teacher may have traveled and observed extensively; a large variety of geographical forms are in his memory, ready to be summoned by name when picturing the stages of the deductive

[1] It has been suggested to me by Mr. Arthur Winslow that the Osage has increased its original meanders in cutting down its gorge. The other rivers here mentioned seem to have done the same thing.

scheme; but no amount of description suffices to place these mental pictures before the class. The best means of overcoming this difficulty is found in the use of the projecting lantern; and now that the electric light may be used in projecting slides on the screen, and the room kept light enough for the class to take notes while the pictures are exhibited and explained, the only thing left to be desired is a good series of views, carefully selected to present typical examples of land forms in various stages of more or less complicated development. These views are not intended primarily to furnish localized examples of geographical forms; although, of course, they have much value in that direction. Their greater value comes from the vividness of the conceptions by which the different kinds of forms and different stages of development of the deductive scheme are held in the mind. The collection of slides that I now use includes a large variety of views; although very useful, it is still imperfect. It should be extended by the addition of many views taken expressly to meet its needs; for the photographs and slides commonly to be had of dealers are as a rule taken with anything but geographical intention. As an indication of the character of illustrations used in a single lecture, I may mention the following examples, and add an outline of the comments made on them.

When the general idea of a geographical cycle has been presented, including the constructional forms with which it begins, and an outline of the destructional forms by which its development is characterized, the next lecture may be devoted almost entirely to illustrations. First, a few slides to show various constructional forms. Muir's Butte, a young volcanic cone in California, introduces a series; it is practically unworn. Its growth was so rapid and so recent that no significant advance in its denudation has yet been accomplished. Mt. St. Elias comes second; as described by Russell, it is a constructional form slightly altered; an essentially young mountain mass. The considerable time required for accomplishment of so great a constructional work may have been enough for the slight dissec-

tion already seen on its surface. While the building of a volcanic cone is spasmodic, almost instantaneous, the uplift of a great mountain is rather slow; its uplift is brief only when compared to the duration of the destructive cycle on which it thereby enters. When first describing the cycle, it was implied that the destructive forces make no beginning until the constructional forces have completed their work. The view of St. Elias corrects that false idea. Several plains follow; all dead level; all ending in even sky lines. The Llano Estacado of Texas, the lava deserts of southern Idaho, the littoral plain of southern New Jersey, the lacustrine plain of the Red River of the North. The areas included in these views show no signs whatever of destructive processes; the surfaces are essentially as flat as when they were born. A pair of drumlins in Boston harbor, and a glacial sand-plain in Newtonville, Mass., as represented in a model by Mr. Gulliver,[1] introduce examples of peculiar constructional forms; and as the more intelligent members of the class soon point out, these might be as fairly included under a consideration of destructional processes as of constructional processes; for they really belong among the "forms taken by the waste of the land on its way to the sea," under certain special conditions, and they will be reviewed in a later chapter of the course under that heading. The drumlins and the sand-plain may also be regarded merely as evidence of a glacial accident during the denudation of the New England plateau.

Passing next to illustrations of young destructional forms, Mt. Shasta is exhibited, with great gulleys worn down its flanks. It is at once pointed out that these gulleys follow lines of constructional slope; that they began as the paths of constructional streams, defined by some accidental irregularity in the form of the volcanic cone; and that they are now slightly advanced in their consequent growth. The Mancos canyon in Colorado illustrates the beginning of the dissection of a plateau; the consequent stream having here cut down a steep-sided consequent valley, but apparently not having yet graded its slope. A

[1] See this Journal, Vol. I., p. 801.

stream in Florida, hardly incised in the low coastal plain, illustrates the faint relief permitted in surfaces that stand but little above their baselevel. The Colorado, in its canyon, is another example of an early stage of development, but it possesses an extreme intensity of relief because of the great altitude of its plateau; not an old valley, but a precocious young valley; not a vast work, except in our inappropriate human measures, but the good beginning of a vast work. The Elbe above Dresden offers illustration of a later stage than the three preceding; it has the beginnings of a flood plain, now on one side, now on the other side of the river; from which it is inferred that the deepening of the valley has practically ceased, that the river is graded, and that the slower process of valley widening is now the determining cause of topographic change.

Views in the Jura mountains would serve as examples of adolescent forms, combining an interesting measure of consequent and subsequent features; but I have not yet succeeded in finding any satisfactory photographs of this region. Features of maturity, more or less advanced, are found in the retreating escarpments of the middle Ohio valley[1] or of the central denuded region of Texas; and again in the minutely carved ranges of the central Alps. For yet older stages, it is difficult to find examples still in the cycle in which their old age was reached; but the plain of the middle Wisconsin river and the plateau of the middle Rhine are ideally satisfactory illustrations of baseleveled surfaces, one being an old plateau, and the other an old mountain region; although both have lately been brought into a new cycle by elevation, allowing their rivers to cut narrow trenches beneath their even surfaces. By selecting views in which only the plain surface is seen, these examples make appropriate closing members of the series here described. At a later time, when the complications of the cycle are in discussion, other views showing the dells of Wisconsin and the gorge of the Rhine may be presented, thus giving a new meaning to old examples.

[1] Not the slopes of the young trench by which the Ohio now cuts across the Cincinnati plain, but the escarpment enclosing the plain many miles back from the trench.

Systematic examination of facts.—While the deductive geographical scheme is thus gradually extended, while its various elements are illustrated more or less completely by blackboard diagrams, diagrammatic models, and lantern slides, an acquaintance with the facts of the subjects is gained at the same time chiefly through the laboratory work of the course. This is for the most part devoted to the examination of maps and many other illustrations of actual geographical forms, introduced systematically to represent the kinds of construction and the stages of development that may be compared with similar kinds and stages in the deductive scheme. I regard it as essential that the two sides of the work should advance together. The theoretical considerations of the deductive scheme and the inductive observation, description and generalization of the facts of nature continually react on each other to mutual advantage. They call different mental faculties into exercise. Neither one can be developed alone to the best advantage. It is true that the consideration of the two sides of the work at the same time leads to mental confusion on the part of untrained or careless students, but this does not seem to me unfortunate. It is, to be sure, rather disappointing for a young fellow to find in the middle of the course that his neglect of its beginning has left him hopelessly behind his better prepared or more persevering comrades ; but it is much more disappointing to see how often collegiate instruction is degraded by allowing it to fall to the reach of students who do not know how or who do not care to know how to follow its proper quality. In work of the kind that I am describing, mental confusion soon overtakes those who are poorly trained for mental effort. I do not find that it makes much difference what subjects a student has been trained in, provided that he is well trained.

Laboratory work is an important element in the study, because there is otherwise no opportunity for deliberate and close observation of geographical facts. Even if shown in the lectures, they cannot be clearly seen, and there is no time then for close study. No text book or atlas contains illustrations in sufficient variety

for collegiate work. But in the laboratory, numerous maps, views, or models may be exposed on walls, racks, or tables, remaining for a week together, and thus giving abundant time for deliberate examination. From week to week a change may be made in the materials, the group for each week corresponding to the group of problems then in hand. Many of the illustrations shown in the first week are repeatedly brought forth again later in the course, always gaining new meaning as sharper outsight and insight are directed to them. Many facts of interest concerning population and occupations may be brought forward in this connection ; but it is important that the geographical facts should first be clearly apprehended.

In the reports that are made on this laboratory work, the students first describe the facts that they have observed, in terms that have no suggestion of explanation. They should not say that a certain region is a baselevelled surface ; but that it is a lowland of faint relief. They should not at first speak of old rivers revived into a second youth ; but they may say that the rivers of a certain region run in deep, narrow valleys below an upland of generally uniform altitude, above which occasional isolated hills rise to greater elevations. This I regard as extremely important, in order to ensure a careful observation of the facts in discussion ; for until the facts are clearly perceived they cannot be precisely explained. It is unsafe at first even to speak of the flat region at the mouth of a river as a delta. This term not only denotes the form of the surface but connotes an explanation ; and in the earlier weeks of the study it is by no means sure that the observer fully perceives all the facts of form that are denoted by the term, or that he fully appreciates all the features of the process that are connoted in its explanation. The outbranching of the distributaries near the river mouth as contrasted with the inbranching of the tributaries (or contributaries, as they might be called), further up stream ; and the faintly convex form of the delta surface as contrasted with the concave form of the upper valley may not be clearly observed, unless they are concisely formulated in a description. The essentially bal-

anced relations of carrying power and load involved in the explanation of the growth of delta may not be perceived unless it is carefully discussed in making out the scheme of river development. There can be no thoroughness of work where observation and explanation are slurred over or confused. After observation and description are well advanced, explanatory terms may be introduced ; it then being seen that such terms imply a pairing off of observed facts with the appropriate members of the deductive scheme. This mental process must become perfectly conscious ; its several steps must be recognized in their proper relations. No strong grasp of the subject can be gained until the student sees clearly where every part of the work stands in relation to the whole.

Topographical maps published by the U. S. governmental bureaus.— It is difficult to secure a full series of facts for laboratory study. My plan at present is to select maps from our own surveys and from the surveys of foreign countries, with little regard to locality, but with much regard to geographical features. The charts of our coast survey offer admirable illustrations of litoral forms. For example, the sand-bar cusps of Capes Hatteras, Fear, and Lookout, and their off-shore shoals, all formed between back-set eddy currents, rotating betwixt the Gulf stream and coast ; or the blunted Canaveral cusp on the Florida coast, and its southward migration from a former position ; or the fjords and islands of Maine ; the sounds of North Carolina ; the delta of the Mississippi, a geographical gem.[1] The maps of the Mississippi River Commission offer remarkable illustrations of the behavior of a large river on its alluvial plain. Its meanders, its cut-offs, and its ox-bow lakes are shown to perfection. The eight-sheet map of the alluvial basin of the Mississippi, prepared by this commission, can be had for a merely nominal charge ; it exhibits the lower part of the great river in an admirable manner. It tells the curious story of streams that descend from the eastern bluffs,

[1] It is not generally enough known that the illustrated catalogue of the Coast Survey Charts may be had free of charge on application by responsible persons to the Superintendent of the Survey in Washington.

but are unable to ascend across the flood plain to the Mississippi ; they therefore unite and form the Yazoo river which runs southward along the eastern margin of the flood plain, near the foot of the bluffs. It would have to pursue an independent course all the way to the Gulf, were it not that the Mississippi comes swinging across the plain, and picks up the Yazoo at Vicksburg.

But it is the topographical sheets of the U. S. Geological Survey that afford the greatest variety of illustrative material for this country ; and it is not too much to say that the facts they present create a revolution in the student's knowledge of his home geography. We may well wish that they were more accurate, but, with all their imperfections, they present a great body of new information. Under the family of plains there are examples of low litoral plains in New Jersey and Florida, the latter being so young that the constructional lakes are not yet drained. The moderate advance in denudation of an upland—itself an old lowland of denudation—is seen in the meandering gorge of the Osage in central Missouri ; the relatively uncut plateaus of Arizona are seen alongside of the beginning of their denudation in the grand canyon of the Colorado. Maturely dissected plateaus are found in West Virginia and eastern Kentucky ; in northern Alabama and northern Arkansas ; but the first two are of minute topographic texture ; the second two are of coarser forms. Outliers of past-mature plateaus are shown on several sheets in central Texas. All manner of other illustrations are found in the same series of maps. The thoroughly adjusted streams of the Pennsylvania Appalachians ; the superimposed streams of northern New Jersey ; the Illinois river, the type of a medium-sized river in the abandoned channel of a large river ; this being the only well-mapped example of the kind in this country ; the warped intermontane valleys of Montana ; Crater Lake in northern California ; glacial lakes in Massachusetts ; flood plains slanting away from their river in Louisiana ; fiords in Connecticut ; moraines in Rhode Island ; drumlins in Wisconsin ; trap ridges in New Jersey ; revived old mountains in North Carolina ; half-buried mountains in Utah and Nevada. Every

new package of these maps brings some new illustration, which is put in use as soon as opportunity allows. One of the latest is a peculiar case in Southern California : a number of small rivers are here seen running down from the Coast range to the shore of the Pacific ; but their mouths are all shut up by sand-bars in the most summary manner ! A curious trick for a Pacific ocean to play on some trifling little streams that one would think were beneath its notice.

These maps are simply indispensable. They call forth much interest from the class. At first hardly translatable into words, their meaning grows plainer and plainer, until at the close of the course they are as suggestive as they were uncommunicative at the beginning.

Foreign topographical maps.—Not less valuable and far more accurate than our own topographical sheets are those of various foreign topographical surveys. Unfortunately the relief in most of these is expressed by hachures ; altitudes being given only for occasional points, or by widely separated contour lines ; but the general expression of the surface is certainly admirably rendered in many of the surveys. The older maps are generally too heavily burdened with hachures ; but the more modern surveys are very artistically executed. It has been my practice for several years past to select certain groups of sheets from the sets of foreign topographical maps in our college library, and order extra copies of these groups, mount them on cloth and rollers, and thus prepare them for the most convenient use in the laboratory. Both the library and laboratory collections of this kind are increasing year by year, and I shall soon prepare a special account of the grouped sheets, in the hope that others may perceive their great value and introduce them as teaching materials as far as possible. Without specifying all that have been thus far secured, I may briefly mention some of the more interesting examples.

From the Army Staff map of France (1 : 80,000) there is a group of sheets showing the level plain of the Landes, with its exceptionally straight shore line and its wide belt of litoral sand

dunes; the beautiful group of radial rivers, flowing down the slopes of a great alluvial fan that has been formed where several large rivers emerge from the Pyrenees, this being one of the best examples of a simple consequent river-grouping that I have found; the plateau of the lower Seine, an old upland of denudation, with an excellent meandering river gorge of moderate depth cut through it, together with certain interesting features of young branching river valleys, and of rivers that have been shortened by the encroachments of the sea in cutting away the land. To these I intend shortly to add groups of sheets showing the dissected escarpment west of Rheims and Chalons, with its beautifully adjusted rivers, the delta of the Rhône, and the fiorded coast of Brittany.

From the Ordnance Survey of Great Britain (1 : 63,360) one set of sheets includes the central Highlands of Scotland, with the Great Glen and Glen Roy; two other sets include the fiords and islands of the southwestern and the northwestern coasts. These three sets agree in showing an old peneplain of denudation, then elevated and maturely dissected, and now somewhat depressed, with cliffs nipped on its land heads and deltas laid in its bay heads. Their formula, according to the plan already suggested, would be 75, + 25, – 2. A glacial accident of late date is recorded by the upland tarns and the valley lakes. A group of sheets for southwestern Ireland exhibits bold mountain ranges running directly into the sea, forming a strongly serrated coast. The English sheets are of older date and are not of particularly good expression, and for this reason I have not yet ordered any of them; although the ragged escarpment of the chalk and of the oölite trending northeast on either side of Oxford should be represented; and the Weald offers excellent illustration of well adjusted consequent and subsequent rivers on an unroofed dome of Cretaceous strata.

The map of the German Empire (1 : 100,000) supplies many examples of striking features. The plateau of the Middle Rhine has already been mentioned as a subject for lantern slides; it is represented in two map-groups, one of which shows the tranverse

gorge of the Rhine ; the other includes the meandering gorge of the Moselle, with a perfect showing of its abandoned cut-offs among the hills. The flood plain of the Rhine about Mannheim exhibits the former meanders and the present controlled course of the river, foreshadowing the future control of the Mississippi ; the morainic country of Prussia is a medley of hills and hollows ; the Vistula turns sharply at its Bromberg elbow from the valley that it once followed, but which it now abandons to the little Netze ; long curving sand bars form the two enclosed bays of eastern Prussia (the Frische and Kurische Haffe). From Norway (1 : 100,000), the district of the Christiania fiord is already received in ten sheets of most delicate execution ; the greater fiords of the western coast will be ordered as soon as fully published. From Russia (1 : 400,000), the lakes of Finland, and of the lower Danube. From Austria, a portion of the flood plain of the Danube, and a strip of the fiorded coast of the northern Adriatic. This is only a beginning of what I hope the collection may be in a few years.

I cannot speak too highly of the educative quality of these grouped sheets. It is, in the first place, a good thing for students to inspect, as closely as they may in laboratory work of this kind, the very best products of geographical art. Their ideals are thus raised above the commonplace level. Whatever they afterwards see will be compared with a high standard. A feeling of dissatisfaction will arise regarding the very inferior maps of their home states, to which they have been inured, and from this a demand will grow for the continuation and improvement of the mapping of our country that is now going on. In the second place, the facts of the subject are placed before the student so closely that he cannot fail to be impressed at once with their real features ; and these he will find so numerous and so varied that he will perceive the need of serious study for their apprehension. No verbal descriptions from the teacher suffice to replace the portrayal of geographical relief on good maps.

Classification of constructional forms.—It is only after the deductive scheme is well advanced, and after many examples of

facts have been correlated with it, that I introduce a classification of constructional forms. Some such classification is essential, but it is difficult to establish satisfactorily, because of the endless variety of structures found in nature. At present in the elementary course I recognize only plains and plateaus of horizontal strata ; mountains of disordered strata, with many minor subdivisions ; and in a subordinate way, volcanic cones and flows, and glacial hills and moraines. Like the more difficult orders of plants in an elementary course on Botany, mountains must be treated briefly in an elementary course on Physical Geography, and their fuller treatment left for more advanced study. After the various kinds of constructional forms are treated, it is advisable to review the features of rivers, with their divides, lakes, waterfalls, flood plains, and deltas ; and in this connection a week or two may be given to the forms assumed by the waste of the land on the way to the sea. The distribution of different kinds of forms should be briefly given with their classification.

When thus developed, Physical Geography may worthily claim the dignity of a University study. Its subject matter is of importance in itself, as well as in its relations to geology, zoölogy and botany, or to history and economics. Its methods are of value in training various mental faculties : observation, description, generalization ; imagination, comparison, discrimination ; these are all cultivated to a high degree in the student who successfully utilizes the opportunities of the course.

Two other aspects of the subject may be briefly considered.

Areal geography.—The study of the fauna and flora of a region or of a continent requires the examination of all of its animals and plants according to some acceptable scheme of classification. The study of the areal geology of a region involves the examination of its formations in their order of local occurrence, but also with regard to the general, world-wide scheme of geological classification. In the same way, the study of the areal geography of a country or of the world calls for the recognition of the parts that compose the whole, of their location and area, and of

their classification according to some rational and comprehensive scheme. Geographical descriptions now current are very defective in the latter respect. They are for the most part empirical; and like empirical descriptions generally, they are short-sighted or blind. One of the difficulties in the way of improvement lies in the need of geological data; for without sufficient information as to geological structure and history, no satisfactory geographical description can be written. It might from this be inferred that, where the geology of a region had been deciphered, the geologist could give an account of its geography as well; but judging by the existing condition of these two branches of earth-science, such is not the case. A great part of the facts that are essential to the geologist are not needed by the geographer. Many considerations that are important to the geographer receive little attention from the geologist. Each is fully occupied in his own special field. Advance in the study of areal geography, therefore, calls first for proficiency in systematic geography, next for a knowledge of general geology and of the local geology of the region to be studied, and finally a special geographical examination of the region. With such a preparation, a course might be planned on the physical geography of Europe, or of the United States; and either course might occupy half a year or a year very profitably. Most of the examples already introduced in the elementary systematic course would here be found again, and many others with them, until the whole area of the country was covered.

Geographical investigation by the state surveys.—The chief difficulty in planning such a course is the scarcity of good geographical material; but, on the other hand, one of the chief interests in geography comes from the opportunities that it offers for new investigations. When we inquire into the generally impoverished condition of geographical teaching in our schools, the main difficulty is undoubtedly to be found in the deficiency of good geographical literature, both in text books and in collateral reading, ready for teachers' use. Consider the case of Ohio, for example. Where shall the inquiring teacher in that state turn

for a rational account of its physical features, presented in the light of modern research? No such account exists. The Empire state is no better off; perhaps not so well. In both these states, as in all others, local physical geography is a most attractive field. It is through this field that the scholars should be led out to see the rest of the world; yet the teachers have not sufficient means of presenting the facts of the subject to their classes. To most persons the facts of our home geography are really unknown. A few investigators, mostly members of geological surveys, possess a more or less intimate personal knowledge of their states; but it is too often stored only in their minds, and there remains inaccessible to others, unless by personal interview. It is indeed rather curious that the state geological surveys have not before now undertaken systematic geographical descriptions of their areas; much more extended than the too brief chapters with which the serious geological descriptions are often prefaced. The geographical descriptions will never be well done until they are made the work of well trained specialists, whose first attention is directed to this subject. The stratigrapher, the petrographer, and the paleontologist are too fully occupied with their own studies to undertake geographical studies at the same time, even if they had the proper preparation for doing so. The effort at double investigation is seldom successful. In the present stage of study it is more economical to give each investigator a single problem over a whole state, than to assign to one person all the problems of a limited district.

It does not seem improbable that in the near future a number of our state surveys may undertake studies in this neglected field, and thus furnish to a new class of readers a fund of material for which they have long been waiting. The teachers of a state will welcome geographical chapters in the annual reports of their survey on the physical features of their home district. The surveys will certainly welcome the new support and interest that will thus be awakened in their work. The geographical chapters may for a time have to be prefaced with introductions, after the

style of those geological synopses by which many of our state reports are opened. The accounts of a certain group of geographical features should always involve the comparison of local examples with those from other regions, much as the paleontologist or the petrographer makes his comparisons of home and foreign examples of fossils or rocks. The chapters must be written in simple style, for many teachers must use them as reference books. They must be well illustrated, for most teachers will have no other pictures of their home district, however well they may be supplied with views of foreign countries. They must, above all, be prepared in accordance with a well considered geographical system. The chapters should not be so long as to fatigue or repel, but rather so short as to awaken an appetite for more reading of the same kind. They should be published not only in the usual annual reports, but also as separate pamphlets for distribution to all schools through the state superintendent of public instruction. Studies of this kind promise to offer most attractive subjects for geographical investigation for many years to come.

There is another and quite different direction in which good work should be done by the trained geographer. That is in the preparation of maps and illustrations for school books. It is manifest enough in examining the maps now in use that they have been drawn by draftsmen, not by geographers. Their lines show no sufficient knowledge of the facts that should be represented. They are simply copies of other maps, with no sufficient expression of meaning. The relief of the land is generally so poorly represented on school maps that no criticism of its execution will make it right; it must be done over again. The outlines of coasts and the courses of rivers are often merely caricatures of the facts. The meaningless irregular curves of Cape Cod and of the Carolina coast offer amusing illustrations of this in many a school geography. The student of geography, who prepares for his work by a good foundation in geology, who carries his geographical studies to the point of original investigation in different parts of the country, and who has a happy

facility in drawing and, if possible in modeling also, may rest assured of a busy future after his apprenticeship. His services will be in demand by more than one publisher as soon as his work is known.

W. M. Davis.

Harvard University, December, 1893.

EDITORIALS.

It has been announced that the Board of Directors of the Geological Survey of Missouri have decided to publish only three more reports, viz.: those on paleontology, on clays, and on lead and zinc; and "to abandon other work on reports on hand, whether nearly completed or not," as well as to discontinue the survey after June 1, 1894.

We hope that this report is entirely erroneous. If it is true, however, those who have followed the history of the Geological Survey of Missouri will hear the news with deep regret. The first appropriation for the present survey was made by the legislature in 1889, and in the fall of that year Mr. Arthur Winslow was appointed State Geologist. Since that time the work of the survey has been rapidly and intelligently developed, and a number of valuable reports have been issued. Though these reports contain a great amount of information, there is vastly more yet which should, and would, if unhindered, appear in later volumes. In the work of a state geological survey the different subjects discussed are not worked up entirely independently of each other, but in the collection of data in the field on one subject, the geologist collects incidentally many facts relating to other subjects which he expects to treat of at a subsequent time. As a result of this, the amount of information on all points of scientific or economic importance is steadily increasing in the office of the state geological survey; and every report that is published means not only that the subject to which it relates has been thoroughly investigated, but also that many facts relating to other matters of general interest have been collected, and will, at some future time, be supplemented by additional facts and form the basis of other reports.

When a survey has completed its work on most subjects and has but little left to publish, its discontinuance, though it may be

premature, is not so injurious as when a survey like that of Missouri, which has just reached maturity, and is in its most active and useful stage, is suddenly discontinued. Great quantities of unpublished information relating to many different subjects and in various degrees of preparation are absolutely lost to the state, for much of such information is necessarily too incomplete to be published without further field work. It has been collected, however, at very considerable expense, and much of it, with a little more time, would be ready to be published and would become of lasting benefit to the state.

By the premature abolishment of a survey, therefore, the state loses not only the money actually invested in these unfinished reports, but it loses the reports themselves, which are on subjects in which almost every citizen in the state is either directly or indirectly interested. More than this, in dispensing with a state geologist and his staff, who for years have been actively and intelligently fulfilling the functions of their offices, the state also loses the benefit of the vast amount of general experience in the region that they have acquired during their investigations. If the survey is ever reorganized, the new officials must not only acquire the same experience over again, at the expense of the state, but they must also collect again the facts lost on the discontinuance of the preceding survey.

The history of many states shows that several times they have organized surveys and then abolished them before the work was completed, or even fairly started; and that perhaps years later they have organized new surveys. In some cases this procedure has been repeated so many times that the advantages gained have cost the state immensely more than they would have done if the first survey had been continued to completion. Missouri itself has had several such experiences, and the friends of the state had hoped, when the present survey was inaugurated, that it would be continued until all its great geological and mining resources had been fully investigated.

In a number of cases, in times of financial depression, state legislatures have been obliged to curtail their expenditures; and

though, as has been shown, it is very unwise to decrease the requisite appropriation for a geological survey, yet if, under such circumstances, it is necessary to do so, the office of state geologist and its incumbent, if he is efficient, should nevertheless be retained, for he possesses facts on unfinished work and a general experience of the region which will mean many thousands of dollars to the state when the survey is reorganized.

It is to be sincerely hoped that the Board of Directors of the Missouri Survey will follow the wisest course. If the finances of the state require the reduction that has been made in the appropriation for the geological survey, let this be only temporary, and let the office of state geologist and its present representative be retained. Mr. Winslow has held this position since the present survey was inaugurated; he has managed the affairs of the survey in a most energetic and capable manner, and the volumes on coal, iron, mineral waters, and other subjects attest to the activity of himself and his staff. Much of this work he has accomplished in the face of the many difficulties that no one but those who have had personal connections with state geological surveys can appreciate; and yet his publications speak for themselves in their completeness and the thoroughly scientific methods with which he has treated the problems before him. He has already performed a great service to the people of Missouri and the public in general; and it is to be hoped that the Board of Directors will not permit the state to lose the man who is more necessary than any other to the successful completion of the geological survey. We recur to the hope expressed at the outset that the report of discontinuance is erroneous.

R. A. F. P., Jr.

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The Boston meeting of the Geological Society of America was remarkable for the large number of papers submitted, fifty-nine, and for the unusual geological activity which these indicated. In an uncommon degree the papers represented recent active investigations. To only a slight extent were they rehearsals of

old studies. Of the fifty-nine papers presented, eleven may be classified as petrological, twenty-two as structural and stratigraphical, four as physiographic, three as paleontological, eight as glacial, four as taxonomic, and the remainder as miscellaneous. On the whole, the papers showed wide diversity of interest and an admirable distribution of investigation. Notable interest was manifested in the petrological papers, particularly those relative to volcanic phenomena, and in the papers bearing on structural dynamics. The titles were as follows:

Some Recent Discussions in Geology. (Presidential address). Sir J. William Dawson.

Geological Notes on some of the Coasts and Islands of Behring Sea and its Vicinity. George M. Dawson.

Fossil Flora of Alaska. Frank H. Knowlton.

New Discoveries of Carboniferous Batrachians. Sir J. William Dawson.

Cenozoic Geology along the Apalachicola River. William H. Dall and Joseph Stanley-Brown.

Geological Activity of the Earth's Originally Absorbed Gases. Alfred C. Lane.

Certain Climatic Features of Maryland. William B. Clark.

Dual Nomenclature in Geologic Classification. H. S. Williams.

Johann David Schoepff, and his Contributions to North American Geology George Huntington Williams.

Relations of Synclines of Deposition to Ancient Shorelines. Bailey Willis.

An Account of An Expedition to the Bahamas. Alexander Agassiz.

Lacustrine Tertiary Formations of the West. William B. Scott.

Geology of the Coosa Valley in Georgia and Alabama. C. Willard Hayes.

Geological Structure of the Housatonic Valley lying east of Mt. Washington. William H. Hobbs.

The Hibernia Fold, New Jersey. J. E. Wolff.

Tertiary Dislocations of the Atlantic Coast of the United States. N. S. Shaler.

Relations of Mountains to Continents. N. S. Shaler.

Phenomena of Beach and Dune Sands. N. S. Shaler.

Eastern boundary of the Connecticut Triassic. W. M. Davis and L. S. Griswold.

Geographical Work for State Geological Surveys. W. M. Davis.

Facetted Pebbles on Cape Cod. W. M. Davis.

Paleozoic Intra-formational Conglomerates. Charles D. Walcott.

Paleozoic Overlaps in Montgomery and Pulaski Counties, Virginia. M. R. Campbell.

The Trias and Jura of the Western States. Alpheus Hyatt.

The Shasta-Chico Series of the Pacific Coast. J. S. Diller.

The Cretaceous Faunas of the Shasta-Chico Series. T. W. Stanton.

Geology of Indian Territory and Texas Adjacent to Red River. Robert T. Hill.

Notes on the Geology of Lower California. S. F. Emmons and G. P. Merrill.

Origin and Classification of the Green Sands of New Jersey. William B. Clark.

Crustal Adjustment in the Upper Mississippi Basin. Charles R. Keyes.

A Geological Study of Lake Mohonk and Lake Minnewaska, N. Y. William H. Niles.

Geologic Relations in the Belt from Green Pond, New Jersey, to Skunnemunk Mountain, New York. N. H. Darton.

A Prismatic Stadia Telescope. Robert H. Richards.

Ancient Volcanic Rocks along the Eastern Border of North America. George Huntington Williams.

Ancient Eruptive Rocks in the White Mountains. C. H. Hitchcock.

The Chemical Equivalence of Crystalline and Sedimentary Rocks. G. K. Gilbert.

Volcanite, an Anorthoclase Augite Rock chemically like the Dacites. William H. Hobbs.

Further Notes on the Occurrence of Albertite in New Brunswick, Canada. H. P. H. Brumell.

Alterations of Silicates in Gneiss at Worcester, Mass. Homer T. Fuller.

Pre-paleozoic Decay of Crystalline Rocks North of Lake Huron. Robert Bell.

Gabbros on the Western Shore of Lake Champlain. James F. Kemp.

Notes on the Occurrence of Mica in the Laurentian of the Ottawa District. Robert W. Ells.

Intrusive Sandstone Dikes in Granite. Whitman Cross.

Age of the Auriferous Slates of the Sierra Nevada. James P. Smith.

Origin of the Coarsely Crystalline Vein Granites, or Pegmatites. William O. Crosby.

A Classification of Economic Geological Deposits, based upon Origin and Original Structure. William O. Crosby.

Lake Cayuga a Rock Basin. R. S. Tarr.

Pleistocene Problems in Missouri. James E. Todd.

Remarks upon a supposed Glaciated Stone Axe from Indiana. G. Frederick Wright.

Pseudo-Cols. T. C. Chamberlin.

Certain Features of the Past Drainage Systems of the Upper Ohio Basin. T. C. Chamberlin and Frank Leverett.

Glacial History of Western Pennsylvania. G. Frederick Wright.

The Ancient Strait at Nipissing. F. B. Taylor.

Extramoraine Drift between the Delaware and the Schuylkill. Edward H. Williams.

Interglacial Series of Germany. Professor Dr. Alfred Teutzsch, Königsberg, Prussia.

The Madison Type of Drumlins. Warren Upham.

Diversity of the Glacial Drift along its Boundary. Warren Upham.

Notes on the Microscopic Structure of Siliceous Oölite. E. O. Hovey.

T. C. C.

Reviews.

Rügen. Eine Inselstudie. By Dr. Rudolf Credner, Professor in the University of Greifswald. Forschungen zur deutschen Landes- und Volkskunde, No. 5, Vol. 7. Stuttgart, Engelhorn, 1893.

Through the special mention of this interesting monograph, I wish to call the attention of studious American readers to the valuable series of essays, edited by Professor Kirchhoff of Halle, and published under the above title. The earlier numbers contain such papers as *Die oberrheinische Tiefebene und ihre Randgebirge*, by Lepsius; *Der Einfluss der Gebirge auf das Klima von Mitteldeutschland*, by Assmann; *Gebirgsbau und Oberflächengestaltung der. Sächsischen Schweiz*, by Hettner; *Die Kurische Nehrung und ihre Bewohner*, by Bezzenberger; *Der Rhein in der Niederlanden*, by Blink; *Die Ursachen der Oberflächengestaltung des norddeutschen Flachlandes*, by Wahnschaffe. The numbers announced to appear shortly are no less attractive: *Die Norddeutschen Urstromsysteme*, by Berendt; *Die Eifel*, by Follmann; *Der Boden von Schleswig-Holstein*, by Haas; *Bau und Entstehung des Harzgebirges*, by Klockmann; *Bau und Entstehung des Erzgebirges*, by Sauer. There are many others of biological or ethnological interest, about forty studies having now been published. The price of the separate numbers varies from one to eight marks. Subscribers who now purchase the whole series may have the first five volumes for half price.

These studies were begun in 1882, in consequence of an appeal to German geographers and geologists issued by Professor Richard Lehmann. A central commission was formed, under which various lines of work were prosecuted. The most important of these are: the *Forschungen*, here referred to; various bibliographic lists, published by local scientific societies, in which everything bearing on home geography is carefully enumerated; and an *Anleitungen zur Deutschen Landes- und Volksforschung*, prepared by various experts. An impulse towards the scientific study of the Fatherland has thus been given, which is bearing rich fruit. The next century ought to see something of the kind in this country; for there is a phase of geologico-geographical literature that is more appropriately associated with unofficial publica-

tion than with reports of state or national surveys. At present, however, the more active state surveys offer the best approach to work of this class, and with the recently increasing interest in physiographical investigation, I hope to see chapters of their annual reports devoted to well illustrated essays of this character.[1]

Rügen, a composite island on the Baltic coast of Prussia, has long attracted attention of geologists from the peculiar dislocations of its Cretaceous strata, in which glacial till was peculiarly involved; so that some observers concluded the dislocations were the product of pressure from the advancing ice sheet. Credner now concludes in effect as follows: The Cretaceous strata, while still horizontal, were overspread by a sheet of till. The compound mass was then, after the disappearance of the ice sheet, fractured and dislocated in a rather irregular manner, although the lines of movement in a measure follow systematic courses. A new constructional topography was thus produced; and a significant advance was made in its subaërial denudation. Then a second ice sheet crossed the Baltic, rubbed over the uneven surface of Rügen, softened its surface expression, and distributed an irregular deposit of drift over the Cretaceous beds and the older drift. Since then, a moderate depression has submerged part of the region, converting Rügen into a group of islands; and these have been in still later times soldered together by sand bars.

Concerning the evidence thus gained of a complex glacial period, Credner remarks: A convincing proof of the long interval between the two glaciations is found both in the heavy fracturing and faulting that took place between the deposition of the two northern drift formations; and in the distinct denudation that was suffered by the constructional forms produced by the dislocations, before the deposition of the second drift (p. 416, 417).

W. M. Davis.

[1] See The Improvement of Geographical Teaching, Nat. Geogr. Magazine, IV., 1893, 74.

Analytical Abstracts of Current Literature.

SUMMARY OF CURRENT PRE-CAMBRIAN NORTH AMERICAN LITERATURE.[1]

Ells[2] gives a description of the Laurentian of the Ottawa district. A reëxamination of the Trembling Mountain section shows that, instead of its being a continuous ascending series, there are no less than three anticlines and their corresponding synclines, and the section is still further complicated by faults of every considerable extent. But one limestone was found, that of Trembling Lake, and this instead of being interstratified with the orthoclase gneiss is in the form of a synclinal overlying this gneiss. This limestone at no point was observed to be more than 50 feet in vertical thickness.

In the region between the anorthosite area and the Gatineau river the limestone in nearly every case occupies well defined synclinals separated by anticlinals of the underlying gneiss. In this area it has been found impossible to trace any bands of limestone to any considerable distance continuously, the limestones being often local in their development, and lenticular in form.

In the limestone in certain places are masses of quartzose rock and crushed gneiss, presenting the aspect of a true conglomerate. As to the thickness of the gneiss, on the Rouge river, the most favorable place found for measurement, the section gave a thickness of 10,000 feet beneath the limestone, if there is no break, but this figure may not be accurate, as faults and repetitions of strata may occur at several places.

Intrusive within the gneiss and limestone are the anorthosite and syenite masses of Grenville and Chatham, and other less conspicuous masses. No less than six or seven clearly distinguished periods of intrusion can be recognized. The augen gneiss of the Rouge river is probably also an intrusive.

[1] Continued from Vol. I., p. 541.

[2] The Laurentian of the Ottawa District, by R. W. Ells. Bull. Geol. Soc. of Am., Vol. IV., pp. 349–360.

The succession in the district, as determined in ascending order, is (1) reddish grey gneiss without distinct signs of bedding or stratification, but with a foliated structure ; (2) reddish orthoclase-gneiss interstratified with hornblendic, quartzose, and garnetiferous gneiss and beds of quartzite, the whole showing a well stratified arrangement of beds ; (3) grayish and rusty gneiss passing gradually upward into the calcareous portion of the system, between the gneiss and the limestone there being interstratifications of the two ; and (4) schistose, sericitic, chloritic, and micaceous schists of the Hastings series. This division overlies the crystalline limestone, and is believed to represent the lower member of the Huronian system. This arrangement of the Laurentian accords very closely with that in New Brunswick, as given by Bayley and Mathew. Unconformable upon the Laurentian of Ontario is the Paleozoic.

Adams[1] describes the anorthosite of Canada, and gives its relations to the surrounding rocks. The great mass of the Archean of Canada is composed of an orthoclase-gneiss, which is in many places laminated, but is in large part little laminated, and probably of eruptive origin. Much of the laminated gneiss is probably sedimentary. In certain regions the laminated gneiss is interlaminated with crystalline limestones, quartzite, amphibolite, etc. This series is a higher part of the Laurentian, and was called by Logan the Grenville series ; while the lower gneiss, which does not bear any of this rock, was called the Ottawa gneiss. The limestone, graphite, etc., are evidences of the existence of life during the deposition of the Grenville series, and this was the earliest life of the planet.

All of the minerals of economic importance occur in the Grenville series. The relations of the Grenville series to the Ottawa series have not been certainly determined, but it is probable that the Grenville series lies discordantly upon the old gneiss, the upper series being sediments originally like those that are deposited to-day.

The anorthosite group, or Upper Laurentian of Logan, is an eruptive rock belonging to the gabbros. It is characterized by a predominance of plagioclase, which frequently is the only mineral of the rock. The rock is hard and originally was completely massive. This original structure has been modified so as to take on an extraordinary cataclastic structure, which has also given the rock a schistose character. This is not ordinary dynamic metamorphism, but is caused by a movement of the rock mass while it was deeply buried and near its melting point.

The anorthosite, although so regarded by Logan, is not a distinct sedi-

[1] Norian oder Ober-Laurentian von Canada, ADAMS, F. D. Inaugural-Dissertation zur Erlangung der Doctorwurde der Universität zu Heidelburg. 1893.

mentary geological formation, but it is discordantly upon the gneiss of the Laurentian by intrusion. Its intrusive character is shown by the following facts: it is a plagioclase gabbro; it cuts across the Laurentian schists; it holds as inclusions blocks of gneiss; about its masses forming girdles are many characteristic contact belts. The areas of anorthosite are isolated, and lie along the border of the Archean continent of that time exactly as the volcanoes of to-day are along the continental borders. In the great interior area of Laurentian no anorthosite has been found. The formation is all pre-Cambrian, as shown by the fact that it lies unconformably below the Cambrian. Also before the Cambrian was deposited it received its metamorphism, and was deeply eroded. Its relations to the Huronian have not been determined, but it probably does not belong to the Huronian period, but rather to the closing part of the Laurentian.

The several regions of anorthosite are described separately, that of Morin and Saguenay being most fully considered. The Morin area is surrounded by the Grenville series. In the Grenville series are interlaminated limestones, bands of which can be traced many miles. Within the limestone are frequently thin layers of the gneiss. The limestone is less resistant and more plastic than the gneiss. As a result of folding, the bands of gneiss have been broken up, producing irregular banded blocks, which are isolated in the limestone in such a manner as to give rise to extraordinary pseudo-conglomerates.

The Saguenay region is of great size, 5,800 square miles. It is surrounded on all sides by the orthoclase-gneiss, or Ottawa gneiss. The anorthosite of this district is more basic than that of the Morin district, the plagioclase frequently being labradorite or bytownite. That it is an intrusive is shown by the same facts as in the Morin area.

Comments.—The time of pre-Cambrian life must have been so vast that it is not safe to assume that the rocks of the original Laurentian bear the remains of the first life of the planet. Indeed, it seems probable that the earliest life left in the rocks no permanent evidence of existence. Further, before it can be assumed that the Ottawa Laurentian bears the oldest remains of life, it must be shown that these rocks are older than any other series bearing life remains.

Adams describes the typical Laurentian areas of Canada.[1] The basement rock here found is the Fundamental Gneiss. It is uniformly reddish or grayish orthoclase-bearing gneissoid granite, poor in mica, and bisilicates. The foliation is often due to movement in a plastic condition. Dark bands of amphibolite

[1] On the Typical Laurentian Areas of Canada, by FRANK D. ADAMS. Journal of Geol., Vol. I., No. 4, pp. 325–340.

are not uncommon, and hornblendic and pyroxenic gneiss appears in some places. The Fundamental Gneiss, so far as at present known, is a complicated series of rocks, for the most part of unknown origin, but comprising a considerable amount of intrusive material.

In certain parts of the Laurentian area, and notably in the Grenville district, the Laurentian has a different character. In the Grenville series the orthoclase-gneiss is still the predominating rock, although it here has a greater variety of mineralogical condition, and is frequently well foliated. Amphibolites, hornblende-schists, heavy beds of quartzite, and numerous thick bands of crystalline limestones, are all abundant and interstratified with one another. In the series are ores, and a wide variety of minerals. In the limestone and associated rocks graphite is often widely disseminated. This does not occur in the Fundamental Gneiss. The areas occupied by the Grenville series while together aggregating many thousands of square miles, are probably small as compared with those of the Fundamental Gneiss. The Grenville rocks, while generally highly inclined, over some large area are nearly horizontal, but even in these cases they have been subjected to great pressure.

As to the origin and relations of the Fundamental Gneiss and the Grenville series, three views may be taken :

1. The Fundamental Gneiss may be the remains of a primitive crust penetrated by great masses of igneous rocks and having been subjected to repeated dynamic movements. The Grenville series may be an upward continuation of the Fundamental Gneiss under altered conditions, marking a transition from a primitive crust to normal sediments. Thus the two would form one practically continuous series. The general petrographical similarity of the two series, taken in connection with the more varied nature of the Grenville series, its frequent stratified character, and the presence in it of limestones and graphite indicating an approach to modern conditions and the advent of life, together with the difficulty of clearly separating the two series from each other and defining their respective limits, lend support to this view.

2. The Grenville series may be considered as distinct from the Fundamental Gneiss, and reposing on it uncomformably, being a highly altered series of clastic origin, the Fundamental Gneiss having some such origin as suggested above or being an older series of still more highly altered sediments. As it is now thoroughly crystalline, there is, however, no absolutely conclusive proof that even the Grenville series is of sedimentary origin. However, the series is in all probability made up, in part at least, and perhaps wholly, of sedimentary material, but as this is not absolutely shown, the proposal to separate it from the rest of the Laurentian and class it as Algonkian or Huronian seems premature.

3. The Fundamental Gneiss may be considered as a great mass of eruptive rock, which has eaten upward and penetrated the Grenville series, while the Grenville series itself represents a series of altered sediments of Laurentian, Huronian, or subsequent age. The world wide distribution of the Fundamental Gneiss (forming as it does, wherever the base of the geological column is exposed to view, the foundation upon which all subsequent rocks are seen to rest) is opposed to this view, as is also its persistent gneissic or banded character.

The anorthosite series is a gabbro, often regularly laminated and much altered, which is intrusive within the Fundamental Gneiss and the Grenville series.

The Hastings series has a very local development. It consists largely of calc-schists, mica-schists, dolomites, slates, and conglomerates, thus containing much material of undoubtedly clastic origin. The whole district has been subjected to great dynamic action, some of the pebbles of the conglomerates being distorted in the most remarkable manner. This series may be equivalent to a part of the original Laurentian, may follow above the Grenville series, or may prove to be an outlying area of Huronian rocks folded in with the Laurentian.

The whole of the above series was cut by various acid and basic rocks, metamorphosed and folded before upper Cambrian time, since the Cambrian sediments rest upon them unconformably, and contain fragments of the lower series which show that when déposited they were in their present condition.

The roche moutonnée surface possessed by the eroded Laurentian rocks was impressed upon them in the first instance in pre-Cambrian times, for along the edge of the nucleus from Lake Superior to the Saguenay, the Paleozoic strata may be seen to overlie such surfaces showing no traces of decay, and similar to that exposed over the uncovered part of the area. To what extent the Cambrian, Devonian, and Silurian seas passed over the Laurentian cannot be determined, but it seems probable that in Cambrian times, a not inconsiderable part of the Archean Nucleus was under water, as shown by various outliers of these rocks. What evidence there is indicates that the area in later Paleozoic, Mesozoic, and earlier Tertiary times, was out of water, being subjected to deep-seated decay and denudation, culminating in the glaciation of Pleistocene times. These processes removed all but remnants of the Paleozoic strata.

Comments.—The question may perhaps be asked whether the visible contacts of the pre-Cambrian and Cambrian are sufficiently extensive to warrant the statement that the pre-Cambrian topography was similar to the present topography. May not the téndency to carry in imagination the present forms under the Cambrian have been given undue weight?

Lawson,[1] in 1893, on lithological grounds suggests the following hypothetical correlation of certain rocks of Western Ontario and Minnesota, Eastern Ontario and Quebec :

	WESTERN ONTARIO AND MINNESOTA.	EASTERN ONTARIO.	QUEBEC.
In order of superposition.	Ontarian system.	Hastings series.	Grenville series.
	Laurentian system.	Ottawa gneiss.	Ottawa gneiss.
	Carltonian-Anorthosites of Minnesota.		Norian.
In order of chronological sequence; an irruptive rock being of later age than the formations which it invades.	Carltonian-Anorthosites of Minnesota.		Norian.
	Laurentian system. { Batholitic granites and gneisses.	Ottawa gneiss.	Ottawa gneiss.
	Ontarian system.	Hastings series.	Grenville series.

Comments.—It seems to the reviewer that such lithological correlations between rocks in different and widely separated geological provinces have no value. The reasons for this belief cannot be here stated, but they have been published in Bull. No. 86, U. S. Geol. Survey.

Barlow[2] describes the Laurentian granites and gneisses as intrusive in the Huronian rocks north of Lake Huron. The localities described are Killarney Village; Beaver, Fox, Balsam, Three Mile, Brush, Camp, Crooked, Johnny, Panache, Wavy, Chief's, Daisy, Baby and Alice lakes; Goshen, Broder and Dell townships; Wahnapital river; Cartier and Straight Lake Stations; and two islands near Thessalon. As evidence of the eruptive nature of the Laurentian gneiss in the Huronian sediments are cited the diverse stratigraphic relations of the rocks along their line of junction; the invariable alteration of the sedimentary rocks along the contact line; the inclusion of angular fragments, clearly referable to the adjacent sedimentary strata in the gneiss; the occurrence of gneissic intrusions and apophyses of pegmatite, occurring in or lam-

[1] The Norian Rocks of Canada, by A. C. LAWSON. Science, Vol. XXI., No. 538, pp. 281–282.

[2] Relations of the Laurentian and Huronian Rocks North of Lake Huron. By A. E. BARLOW. Bull. Geol. Soc. of Am., Vol. IV., pp. 313–332.

inated with, and cutting across the bedding of the Huronian rocks; the absence of sedimentary rocks within the gneiss, and the general character of the gneiss, which in appearance and behavior more nearly resembles an eruptive granite than an altered sedimentary rock. It is therefore concluded that the Huronian is the oldest series of sedimentary strata in this region, and that the floor upon which these were lain down must have been subsequently fused and recrystallized.

Comments.—That in many localities there are granites and gneissoid granites intrusive in the Huronian of Lake Huron has been well known since the days of Logan. However, because a part of the granites are intrusives later than the Huronian, this does not show that the basement upon which the Huronian was laid down does not still exist, in part at least, as held by Logan, Irving, Pumpelly, and others. The account of the facts and their interpretation at the contacts near Thessalon by Barlow are so irreconcilable with those given by Pumpelly, Irving, and myself, that the former or the three latter must have wholly failed to grasp the truth. These latter hold that there is here the most manifest evidence of profound unconformity between the Basement Complex and the Huronian. Should this position prove correct, the question would naturally arise as to what extent the accounts of the remaining localities described by Barlow need revision.

Smith,[1] in 1893, gives a general description of the Archean rocks in the southern half of the Rainy Lake district in the Province of Ontario, between the Thunder Bay district and the Lake of the Woods. The rocks here found are divided into the Lower Archean and Upper Archean, the term Archean being defined to include all pre-Cambrian rocks. The Lower Archean series, or Laurentian, comprises a lower granitic and syenitic division, and an upper micaceous, hornblendic and trappean division, for the most part schistose. The first usually occurs in rounded or ovoid areas, between which are the rocks of the Upper Archean or Ontarian.

The Ontarian system includes the Contchiching and Keewatin series. The Contchiching rocks are mainly mica-schists, and have an estimated thickness of 9,000 feet, the apparent thickness of 24,000 to 29,000 feet, given by Dr. Lawson, being believed to be due to multiple folds. These mica-schists are regarded as clastic in origin, because of their fine and even lamination. The Keewatin consists for the most part of plutonic, volcanic, and pyroclastic rocks, although in some of the upper members there are more or less aqueous sediments. The Contchiching and Keewatin are everywhere in strict conformity, although at the base of the Keewatin in certain localities there are conglomerates regarded as local and volcanic.

[1] The Archean Rocks West of Lake Superior. By W. H. C. Smith. Bull. Geol. Soc. Am., Vol. IV., pp. 333–348.

The Laurentian granites and gneisses are intrusive in the Ontarian, and are therefore younger, the relations between the two being the same as described by Lawson in the Rainy Lake district.

Resting discordantly upon the Laurentian and Ontarian rocks, is the Steep Rock series, presumably of Archean age. This series is believed to be a folded syncline, rather than a monocline, as described by Smyth. As the Animikie series exhibits no such folding, the inference is strong that the Steep Rock series is older than the Animikie. While the unconformity between the Steep Rock series and Laurentian is undoubted, the unconformity between the Keewatin of the Seine river and the Steep Rock Lake series is not at all obvious. Lithologically the two series are strikingly similar, and could not be separated by the most careful study. It would seem that to the west of Steep Rock Lake this series has been faulted up and swept away, so that it is really unconformably above the Keewatin. The Atic Oban series is an eruptive one probably belonging to the Keewatin.

Comments.—Since the Steep Rock Lake series is almost identical in character with the Keewatin, the assumption of profound faulting and erosion to explain the absence of the former series west of Steep Rock Lake seems purely gratuitous, the natural explanation being that the two are the same, and that the discordance at the base of the Steep Rock series is marked in other localities by the occasional conglomerates described by Lawson and Smith at the base of the Keewatin. That unconformities are partly obliterated or difficult to discover when the discordant series are closely folded is well known, and that a break, if such exists at the base of the Keewatin, should be so strongly marked everywhere as at Steep Rock Lake could not be expected. A conglomerate in itself is of course no evidence of unconformity, but the conglomerates at the base of the Keewatin are of such a character that Dr. Lawson, who has studied the district, believes that they mark, if not a real unconformity, a profound change of physical conditions between the Contchiching and Keewatin. Also he holds that these conglomerates are sedimentary, rather than volcanic.

Fine and even lamination, it may be said, is not sufficient evidence that the rocks showing this structure are clastic. Such structures are found both in metamorphosed igneous and sedimentary rocks. Moreover, it cannot be assumed that such a structure corresponds with bedding, even if the rocks are clastic. Hence, until it is shown that the two do correspond, determinations of thickness based upon lamination can have little value.

Buell[1] describes and maps the Waterloo quartzite areas. These are a series of detached outcrops resting unconformably under the Lower Silurian

[1] Geology of the Waterloo Quartzite Area. By I. M. BUELL. Trans. Wis. Acad. Sci., Vol. IX., pp. 255–274.

of Southern Wisconsin. Within the quartzite are occasional layers of conglomerate. The different outcrops are apparently parts of a synclinal fold. As a result of the shearing much of the quartzite has been crushed, and sericite has developed.

Van Hise[1] considers the dynamic phenomena shown by the Baraboo quartzite ranges of Central Wisconsin. These rocks, indurated by cementation, exhibit all stages between massive quartzite showing microscopically little evidence of interior movement, through a rock having in turn fracture and cleavage, to one which is apparently a crystalline schist, but in thin section still giving evidence of its fragmental origin. The schistosity produced by the movement of the layers over one another is parallel to the bedding. In places *Reibungs* breccias have developed. At one point minor faulting was noticed. These phenomena are more marked in the North Range than in the South Range, and thus bear in favor of Irving's explanation of the structure as a part of a single great fold in a set of layers 12,000 feet thick, the North Range being on the leg of the fold, and thus requiring greater readjustment of the beds than those on the South Range, which are near the crown of the anticline.

Winslow,[2] in 1893, places in the Archean the granites, porphyries, and felsites of Missouri, and in the Algonkian the associated conglomerates, one of them bearing the Pilot Knob iron-ore.

Keyes,[3] in 1893, holds that the granites of Maryland are eruptive, since these rocks indiscriminately cut across the other igneous rocks of the region, as well as the gneiss ; because they hold inclusions of the other rocks of the region ; because the rocks cut show contact phenomena, and because a microscopical examination shows that they possess all the characters of rocks cooled from fusion.

Smyth,[4] in 1893, describes the rocks of Gouverneur, N. Y. The gneiss gives evidences of mechanical deformation in the shattering of the quartz and

[1] Some Dynamic Phenomena Shown by the Baraboo Quartzite Ranges of Central Wisconsin, by C. R. Van Hise. Journ. of Geol., Vol. I., No. 4, pp. 347–355.

[2] The Geology and Mineral Products of Missouri, by ARTHUR WINSLOW. From "Missouri at the World's Fair." (Official Publication of the World's Fair Commission of Missouri).

[3] Some Maryland Granites and Their Origin, by C. R. KEYES. Bull. Geol. Soc. of Am., Vol. IV., pp. 299-304.

[4] Petrography of the Gneisses of the Town of Gouverneur, N. Y., by C. H. SMYTH, Jr. Contributions from the Geol. Dept. of Columbia College. Reprinted from Transactions of the New York Academy of Sciences, Vol. XII., pp. 203–217.

feldspar particles. Within the feldspar, along the cracks, microperthite has developed which does not show any dynamic action. The granite is much later than the gneiss, but like it has to some extent suffered from dynamic action. In general it is massive, or nearly so, but there are zones of shearing where granulite and gneiss have developed. Also in one portion there is a dark rock approaching a diorite, into which the granite grades, but this is regarded as a basic segregation from the original magma. The crystalline limestone is rather uniform in its character, but where intruded by the granite, it is more coarsely crystalline, and various metamorphic minerals have developed. Near the base of the limestone is a pyroxenic rock which is schistose, highly contorted, and is of somewhat doubtful origin, in the field being regarded as sedimentary, and under the microscope having an appearance which suggests an igneous origin. In this pyroxenic gneiss occasionally scapolite is found. The Potsdam is a pure vitreous quartzite, indurated by the process of cementation.

Nason,[1] in 1893, describes the gneissic rocks bearing iron-ore in the Adirondack region as precisely like the Mt. Hope type of rock, bearing the New Jersey magnetites, and it is thought that the two are probably contemporaneous, bedded deposits. These gneissic ores are non-titaniferous, and are to be discriminated from the titaniferous iron ores which are associated with the labradorite rocks or norites of the region. These in occurrence and association are wholly distinct from the ores belonging in the gneisses.

Lawson[2] describes the Santa Lucia granite of Carmelo Bay as resting unconformably below the sedimentary rocks (Miocene) of the Carmelo series. At the base of the latter is a fine basal conglomerate. Across the Bay of Monterey, in the Santa Cruz range, granite without doubt of the same geological range bears a similar relation to rocks which are of not later age than Cretaceous. The granite is therefore, at the latest, of pre-Cretaceous age.

C. R. VAN HISE.

[1] Notes on Some of the Iron-bearing Rocks of the Adirondack Mountains, by F. L. NASON. Am. Geol., Vol. XII., No. 1, 1893, pp. 25–31.

[2] The Geology of Carmelo Bay, by A. C. LAWSON. Bull. Dept. Geol., Univ. of Cal., Berkeley, Vol. I., pp. 1–59.

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(Further acknowledgments of pamphlets already received will be made in the next number.)

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THE GLACIAL SUCCESSION IN NORWAY.

As SCANDINAVIA was unquestionably the chief center of the great North European glaciation, it follows that Norway is a country of glacial denudation rather than of glacial deposition. A complete apprehension of its Quaternary history is, therefore, not possible solely through the study of the deposits. The great marks of erosion are to be taken into consideration. We thus come immediately upon the great problem: How far are we to go in our acceptance of glacial erosion? It is of course impossible here to enter into the whole vexed question. It is, however, necessary to briefly summarize some of the reasons which lead the geologist in Norway to admit an erosion of so great degree, that both our fjords and lakes fall wholly within its limits. The most convincing argument is, perhaps, the fact that the great North European diluvial plain contains Scandinavian detritus in such immense quantity that the rock basins in Scandinavia could be refilled and replenished many times with it. A. Helland has calculated that the German and Russian diluvial sheet could fill not only the Scandinavian lakes, but also the Baltic, and still heighten the whole peninsula 25 metres (80′). And besides, we have the enormous quantity of Norwegian rock detritus which forms the bottom of the North Sea and the broad submarine plateau to the west of northern Norway. Even if this estimate is not entirely correct, it is impossible to deny that such enormous quantities of drift have been removed from Norway in Quaternary time that we must look for marks of denudation of quite as great degree as our lakes and fjords.

An estimate of the volume of rock matter which is carried by the glacial rivers of Greenland and Norway proves also that the glacier denudation in a few thousand years must reach great dimensions.

When thus the capacity of the rock basins comes short of holding the known glacial sediment (the quantitative element), the form of the basins (the qualitative element) is quite in harmony with those we find in other glaciated countries and *nowhere else.* Both the lakes and the fjords have a distinguishing trough shape, with flat bottoms and comparatively steep sides, in the transverse section, and, in the longitudinal section, a gradual deepening toward a point that is situated not very far from the outer end, against which it more suddenly shoals up. This form cannot be generated by any other possible eroding agent than glacier ice. The fissure theory is out of the question, as exact sections specifically show. Faults and dislocations cannot account for their specific form and their relations to quite superficial topographical features. The admirable monograph on the Kristiania fjord, by Professor W. C. Brögger, makes it also quite clear that its distinguishing fjord character can only be of glacial origin. Basins of this form, as is well known, are restricted to glaciated countries; and they can be deduced directly from the motion of the eroding glacier. The movement must accelerate towards the point where the ice surface intersects the snow line, where the surplus ice from the whole glacier must pass. Thence it must slacken because of the melting farther down. The erosion, which naturally must depend both on the movement and the pressure of the ice, will decrease accordingly. In this we find the explanation both of the longitudinal form of the glacial basins, and of their evident dependence on the margin of the land ice.

So much may be said about glacial erosion by way of introduction before entering into the study of the succession of glacial events in Norway. We must be somewhat prepared to face the greatness of the phenomena, which only glacial studies can make more familiar to us.

When we try to realize the appearance of Norway in *pre-*

glacial time,—*i. e.*, before the Quaternary age—we have not much on which to base our ideas. The immense denudation has so thoroughly altered the physiognomy of the country that we are quite at a loss to reconstruct it. We can only suppose that no great change in the relative heights of the mountain plateaus has taken place and that there are left, perhaps, in the mountain bosses remnants of the original surface. The coast line we are no doubt justified in putting farther outwards than now. The great slope to the ocean deep does not follow the present coast, but is up to 200 kilometers distant, the intervening bank not reaching beyond 400 meters. The flora and fauna of Spitzbergen and Iceland must have immigrated across this now sunken north-western foreland. Near Storeggen (about 62°) G. O. Sars found, by dredging at 100 to 200 fathoms (200 to 400M.), remains of a littoral fauna and beach shingle, which can only belong to a pre-glacial coast. It must therefore be a legitimate inference that the country in late preglacial times was, at least at the coast, 200 to 400 meters higher than now.

On the mountains in this high country there now began to gather great snow masses, the climate deteriorating owing to causes that cannot be treated here.[1] The névés gradually coalesced and the glaciers flowed down to the lower land. If the present numerous fjords had a preglacial existence they must have represented themselves as a close series of deep lakes or fjords into which the glacier soon crept. But beyond such a row of ready outlets no continuous ice margin could possibly grow. The depth of Sognefjord is 1,250 meters, of Hardangerfjord 800 meters, though both are rather shallow at their mouth. If the whole country was elevated 200 to 400 meters, we still would have so deep waters, that any glacier, which could not at once move forward with a thickness of 1,000 meters, would get afloat and be dissolved into icebergs as fast as it could grow. So any advance of inland ice (which necessarily increases but slowly) must

[1] I have given my reasons for accepting a shifting of the pole as cause of the ice ages in a paper: Strandlinje-studier in Archiv foı Mathematik og Naturvidenskab Kristiania, 1890–91, T. 9–10.

needs be impossible farther out than at the innermost fjord heads The greatest distance between the heads of any two neighboring fjords on the whole Norwegian coast is only about 60 kilometers (less than 40 miles), and an ice stream driven out over this neck between Sognefjord and Nordfjord could not by any means reach a height of 510 meters at the isles in the mouth of Sognefjord, where we find glacial grooves and foreign boulders 1,760 meters, 5,700 feet above the fjord bottom. With only 20 to 30 kilometers to discharging outlets on each side, its thickness would ever be small. The fact must be kept in view that the inland ice behind, from which the ice stream flowed, had only a very inconsiderable breadth. The distance from the fjord heads to the present watershed is nowhere more than 30 kilometers, and the want of boulders transported from the country more to the east proves that the ice-shed, the glacial divide at the glacial period, could not have been situated far from the watershed. Now a névé less than 30 kilometers broad could never have pushed a continuous margin beyond a close set row of deep fjords. As we now in southern Norway actually find the whole west coast, except the highest points, very strongly glaciated, we are forced to admit that the only state of things in which the ice could have advanced so far west is to be found in a country where depressions, of a volume in any degree comparable with the present fjord system, are wanting. We are obliged to ascribe the formation of our fjords to Quaternary forces—that is, glacial erosion.

We know that boulders from the Kristiania fjord are found in the till as far away as North Netherlands and at Holderness, in England. We further know that the east-going ice flow in Scotland was turned back in Sutherland and that Orkney and Shetland were glaciated from the east, *i. e.*, from Norway. A continuous inland ice could not have grown gradually across the deep Norwegian channel, which encircles southern Norway, the deep sea basin reaching 900 meters. As in the case of the fjords, we must also conclude that this fjord-like basin (which indeed does not reach the depth of some of the fjords) did not exist in preglacial times, but owes its origin to the ice stream that flowed

outwards in it, following the line of least resistance for the ice overflow in central Scandinavia. This only need be 1,500 meters thick to be able to erode the bottom when the maximum erosion was in progress. This ice stream turned round the Naze and left its bottom moraine also on the southwestern Norwegian coastland, *e. g.*, on Jaederen, where boulders from the Kristiania territory are very numerous.

While the extreme eastern margin of the first great inland ice, as demonstrated by the extension of the boulder clay, reached to Kiew and Petschora, we must thus place the western margin at the steep slope to the Norway deep in the North Atlantic Ocean. But we have reason to think that it did not remain there for a very long time. As the weight of the ice increased the land was obliged to *sink* below it. This follows not only from the general physics of the earth's crust as demonstrated by O. Fisher, but can also be directly deduced from facts observed in all former glaciated countries. Invariably when there comes an inland ice there follows a depression; with the melting of it there is everywhere a re-upheaval; and everywhere the amplitude of the crust motion is in close accord with the thickness of the ice sheet.[1] Under the great first inland ice, Norway sank and therewith came a raising of the snow line in relation to the ice surface and an aggression on the ice from the rising sea. Under these circumstances the ice margin was forced back, and many things indicate that it at length took up its position at ab ut the present coast line and paused there while the great terminal glaciers flowed down preglacial depressions and made new ones and scooped out, by long continued action, our grand fjords. Judging from their form and great dimensions, this erosion took place under very constant circumstances. The ice must have kept its place for a very long period constituting, in all probability, the greater part of the first great ice age. It might be objected that when the ice receded by the sinking of the land, the crust upheaval must have followed immediately. As the sea with its

[1] This I have followed out from the known glaciated countries in my Strandlinje-studier, but cannot in this place re-state it more fully.

greater specific gravity in a great degree replaced the melting ice margin, the consequence appears to have been that the land finally lost in height perhaps as much as 200 to 400 meters. We shall find analogous phenomena in other glaciated countries.

The thickness of the inland ice in Norway at this time we are able to estimate by the upper limit of foreign boulders and by the lower limit of the rocks on mountain summits which were not reached by the ice sheet. Where a great continuous scoring ice sheet has worked we find in Norway, as in Greenland and elsewhere, the smooth undulating surface lines with fresh rock surfaces. Higher up, above the reach of ice, we find the *nunatak* formation with peaks and cirques (botner) and with highly weathered rocks and mighty talus and other debris. By such limits we can approximately determine that the maximum height of the ice sheet in southern Norway was below 2000 meters, in northern Norway about 1200 to 1500 meters, these being reckoned from the present sea level. As the mean height of the Norwegian highland may be estimated at 800 to 1000 meters, and as only central Norway reaches more than 1200 meters, we get an ice sheet which, near its axis, will measure only about 800 to 1000 meters. To this thickness of the ice the depression of the land answers very well according to O. Fisher's theory.

The first great Quaternary glaciation of Norway was followed by other great climatic changes. To get a more handy terminology than the common periphrastic nomenclature, I have proposed, for the most pronounced periods, the names *proteroglacial* for the earlier great ice age as distinguished from the well-known last great glaciation that followed—the *deuteroglacial*. I have chosen and press for acceptance at the Congress terms implying the first and the second of *two* periods because these two glaciations seem to be demonstrable for all glaciated countries. The names cannot well be misunderstood, and if, perchance, as some American and German geologists assume, a third separate glaciation can be proved, it will be easy to give it a name apart. So far we can only distinguish in Norway preglacial, proteroglacial,

interglacial, deuteroglacial, and postglacial periods, all very clearly denoted by these names.

The proteroglacial period came at last to an end. The ice retired very much; an interglacial period followed. Of this warmer period we know very few certain traces in Norway. Almost every deposit referable to it has been swept out by the last —the deuteroglacial—ice sheet at least in the parts best studied. At Jaederen we certainly have some layers of gravel and sand between the undermost bottom moraine carrying boulders from the Kristiania territory, and the uppermost one bearing boulders from the mountains close by on the east, but these layers do not contain, as far as known, any fossils giving information about the climate, and it may very probably be that they must be referred to the retiring proteroglacial or the advancing deuteroglacial ice.

The part of the proteroglacial country which was not covered by the deuteroglacial ice sheet or sea—and which, therefore, might have retained interglacial deposits—is very poor in loose matter and it has, as yet, not been possible to distinguish any interglacial debris. In the center of the country at Våge, near the highest mountains in Norway, there was some years ago found in river gravel a molar of the mammoth. It may now be said, that this tooth is certainly neither postglacial, protero- nor deuteroglacial, as the tract in these periods was quite ice-covered. There remains the assumption that it is preglacial or interglacial, and as it is not very probable that this molar has remained unmolested through the very long first glaciation by which the whole country was deeply eroded, it is perhaps permissible to take it for interglacial. In this case we may conclude that the country in interglacial time was covered with forest up to the highest plateaus; and, therefore, the *proteroglacial inland ice was entirely gone.*

It is, however, more reliable to seek for support by a comparison with neighboring countries. The peats in parts of Denmark not deuteroglaciated show an arctic flora with *Dryas, Salix polaris, herbacea,* and *reticulata,* which followed the great retreating proteroglacial ice sheet, and this was superseded by a vegetation char-

acterized by *Populus tremula*, and this again by a *Pinus sylvestris* flora.

Above the layer with Pinus comes a new one with oak and finally the surface stratum with recent forest trees. Now in the peats of deuteroglaciated Norway and Sweden we always find the oak layer on the bottom (with a layer of pine and birch above), which shows, without doubt, that the preceding vegetations in Denmark and Scania must be interglacial. To judge from the aspen and pine forests it might be concluded that the interglacial climate in Scandinavia was somewhat colder than the present, but the melting of the ice may have required a higher temperature and the fossils from layers between the two bottom moraines in the Baltic countries bear a rather southern stamp.

We come to more reliable ground when we advance to the last great glaciation in the *deuteroglacial period*. Again the snow gathered on the high mountain plateaus, again glaciers pushed forward towards the lower ground accompanied by a severe climate. But the glaciers this time were met almost at the watershed by the deep proteroglacial fjords which necessarily must put an end to their advance westward. The continuous western ice margin could not reach beyond the fjord heads. To the east, however, the way was free for the growing inland ice. The consequence of this was that the *ice sheet* divide crept eastwards and reached a line up to 130 kilometers southeast of the land watershed. Here at last the resistance to the glacier motion was alike on both sides of it. *We therefore find the boulders in deuteroglacial time* —in contrast to the distribution in proteroglacial time—*transported across the watershed from lower ground in southeastern central parts* up hundreds of meters to the divide and borne on as far west as the deuteroglacial ice and its icebergs went.

To the west we find the ice margin determinated by the fjords, to the east it pushed forward out to the coast line by Skagerak. We find its margin, as in the case of the deuteroglacial ice in North America, marked by a long terminal moraine—raerne—from Arendal to the Kristiania fjord and thence to southeastern Sweden.

Also in Finland we find a terminal moraine near the south coast. But through this terminal moraine there crept out a very long Baltic ice tongue which reached down to Brandenburg and the eastern part of Schleswic. Behind the terminal moraine in Norway we find a series of lakes eroded, here as elsewhere, near the ice margin, but these lakes are rather small and have no relation to the present valleys behind. It is therefore reasonable to suppose that the inland ice did not have any very considerable thickness here when it reached this extreme limit and also that the valleys were not yet fully developed.

As in proteroglacial time, the country again sank under the ice weight and again the ice sheet retreated with the relative raising of the snowline, and advance of the sea. The retreat is near Kristiania fjord marked by three or four discontinuous moraine lines with, in places, rather large lakes behind (Oiern, Tyrifjord, Norsjö). But in Norway—as in America—a final position was not reached before the great marginal glacier was settled in what was to become a fine row of great lake basins: Solör (filled up), Mjösen, Randsfjord, Sperillen, Kröderen, etc. This most constant phase of the deuteroglacial time deserves a particular name. I have called it the *Epiglacial* epoch, as it closes the great glacial series. It is parallel to the American Champlain epoch, but as American geologists (Dana especially) regard the Champlain epoch as postglacial, I have not ventured to accept the name.

In southeastern Norway we find the terminal glaciers ending in the greatest lake basins in the country; in western and northern Norway the glaciers were, as above explained, stopped by the fjord heads. But here we also find that the glacier ends everywhere once occupied smaller but yet deep lakes, with bottoms often below the sea level, just behind the fjord heads. When we in Norway have more than 100 such lakes cut in the rock just where the glaciers terminated, I cannot see how it is possible to evade the conclusion that these lakes must be of glacial origin. It will not do to suppose that this coincidence of so many lakes and glacier ends is the merest accident. The relation must needs be genetic. The form of the lakes is the typical trough with a longi-

tudinal section in the best accordance with the probable distribution of the erosive power in a glacier.

The rock matter which was scooped out by the epiglacial glaciers was deposited partially as terminal moraines, but mostly as terraces in the fjords. We therefore now find the epiglacial lakes everywhere separated from the fjord heads by some kilometers of terrace land. These great upper terraces mark the level of the epiglacial sea. Their height differs very much in the different districts, and it was first by the study of the corresponding ancient sea beaches that I was able to find the correlation between them. In western and northern Norway, these ancient sea margins are very distinctly marked, often in the living rock. As might be expected, in accordance with the theory of isostasy of the earth's crust, these lines are now raised towards the former center of the ice sheet, from which the maximum ice load was taken away. Nearest this point the epiglacial sea beach and terraces now reach 200 meters above the sea, with a gradual fall towards the outer coast, where their height is only some 20 meters or less. The gradient in the fall is much greater than in Lake Agassiz, reaching 1.2 meters (4′) per kilometer, against 0.10 meters (20″), but it is clearly the same cause that has been at work in both cases.

The height of the deuteroglacial ice sheets seems to have been almost the same as in the proteroglacial—less than 2,000 meters maximum above the present sea level.

The epiglacial terraces contain in some places banks of shells with quite an arctic aspect. The deeper clay has *Leda artica* as its leading fossil. The climate must have been very like that at present in South Greenland, and the topographical physiognomy must also have been very much the same, with a partially alpine foreland (which constituted nunatak forms as in the proteroglaciated epoch), and with glaciers at the heads of the fjords, with great clay bars or deltas before them, and with small floating icebergs to score out the strandlinjer—the sea beaches in the rock.

It is altogether probable that a meteorological map of Nor-

way in epiglacial time was very like a modern map of Greenland. The isotherm of 0°C. for the year must have followed the southern coast perhaps as far up as to the polar circle. The lower isotherms must have enclosed a pronounced minimum to the east of the ice shed, where certainly — 20°C. must have reigned.[1] While the difference from the present mean temperature at the coast was only 5 to 6° C., the difference near the pole of maximum cold must have been 15° C. at least. This great difference, which is a necessary consequence of the contrast between coast climate and the pronounced continental climate over the east side of the great ice field, is as yet not sufficiently noted by the students of glacial time. An exact consideration of the distribution of the meteorological elements above the inland ices will give the solution of many glacial problems. I shall here only remark that the snowfall in this continental region must have been almost imperceptible as in winter in Siberia now—and likewise the melting. Now, the power which keeps the glacier in motion is ever the surplus of snowfall. The whole continental side of the inland ice must thus be kept in quite a passive motion, be pushed as a rather thin ice plate out to the margin by the press from the greater snowfall on inside ice nearer the ice shed and the coast. The reliable measures of the ice sheet in the Baltic show really very small dimensions—less than 200 meters—thus it will become intelligible why the greater ice masses to the west can keep the ice divide four to six times nearer the western margin. An ice plate of about 100 meters or less must be impotent to erode. The bottom moraine from the more powerful inner part must be gradually built up *below* the outer thin marginal ice sheet. On the continental side we will have formed a regular boulder-clay or thick bottom moraine outside an area where denudation in the form of broad shallow basins or plains will still take place—all this against the deep rock basins with terminal moraines and terraces before them, on the coast side. The snowfall here will be very great. The surplus ice

[1] Cf. H. MOHN's meteorological map of Greenland in Wissenschaftliche Ergebnisse, von Dr. NANSEN's, Durchquerung von Groenland, Gotha, 1892.

will be carried with considerable speed by steep glaciers to the sea; the localized erosion will be very energetic; and we will get the fiords and the lakes—while the eroded matter will only be deposited *before* the glaciers as terminal moraines and terraces.

As the ice shed will be rather near the coastward margin of the inland ice, it follows that it is for a great part the enormous snowfall on the great western glacier's own surface which is to be transported. Hence these glaciers can follow more irregular lines from the first, only deepening and widening the preëxisting valleys, and so we get the complicated fjord systems; while, on the continental side, where a more uniform *vis a tergo* pushes the ice plate forward, the eroded depressions must be more regular. It is quite necessary to keep in view this great contrast between erosion and deposition on the part of the continental and the coast sides of the great ice sheets, respectively, in order to be able to understand many of the complicated glacial phenomena.

We have seen that the deuteroglacial and especially the epiglacial inland ice had its ice shed far to the east from the watershed. Across this divide the ice must move and with somewhat accelerated speed in the narrow defiles. There must here originate passes or gaps (skar in Norwegian) across the watershed. Of these, we really have very many in Norway with a development in distinct relation to the distance between the ice-shed and the watershed and to the greatness of the epiglacial lakes and valleys on both sides. In not a few we have lakes with outlets on either side.

When the ice stream through such a gap came out to the western edge of the high plateau, there resulted a sort of ice cascade, which, like a waterfall, receded with rather great speed. These receding icefalls evidently gave origin to most of our *fjord-valleys*, *sack-valleys*, *culs de sac* interior to the fjord heads. Also these must generally be of deuteroglacial origin, as only then the ice flowed in great streams across the watershed.

The epiglacial stage of the deuteroglacial period must have had a very abrupt termination. The glaciers retired from the

epiglacial lakes without filling them up in any considerable degree. The ice melted so speedily away, and the crust swelled up so fast, that the deposits of the rivers just below the epiglacial terrace level are very small. This could only occur with a climate more genial than the present in which an existing glacier as great as the epiglacial land ice would certainly assert itself with success.

We must suppose a considerable uplift of the snow line in this time which followed the epiglacial period, and which I shall call the *Boreal period.* Such a genial climate in early post-glacial time we are forced to assume also on biological reasons. On the warm valley sides in the western interior fjords, we find many plants which can only prosper in a temperature more than 2° C. higher than now prevails in the intervening tract across which they must necessarily have immigrated. On the southwestern coast flourished a vegetation almost like the Irish coast flora, but separated from its main habitat by a temperature perhaps 4° C. lower in January than it will bear. These Boreal and Atlantic plants can only have spread to their isolated places in Norway in a climate some 3° C. warmer than the present. That this warmer time did occur in early post-glacial time is again proved by the stratification in the peats, where the plants most susceptible of cold (ash, oak, etc.) are found in the deepest layer or rather on the bottom itself—this also in places on the coast and in the mountains where now no forest tree grows.

These 3–4° C. recorded by the vegetation would certainly have raised the snow line, which now is 1200 to 1800 meters above the sea in Norway, above almost the whole epiglacial ice sheet, which nowhere attained 2000 meters. The great inland ice must then have become a *dead* glacier, and must have melted rapidly, especially from the margins. The last remnants of it might be supposed to have been situated near its maximum elevation, *i. e.*, near the ice shed. This lay, as explained above, in deuteroglacial time at some distance to the southeast of the land watershed, as the many boulders in the upper eastern valleys which were transported upwards prove. The ice remnant is then to be

sought for as far as 100 kilometers to the east and south of the watershed. This southern position was moreover accentuated by meteorological facts. The western moist winds are intercepted by the broad western alpine foreland and the high land near the watershed, while the low country at the southeast would give the moist winds free access to the southern glacier side. The country close to the watershed on the southeast now gets almost all its humidity from the southeast winds, but these would, in early post-glacial time, be barred by the inland ice, which in this way would come to have a very dry north side, in contrast to a very moist south side. This would draw the last inland ice out to the southeast edge of the mountain plateau to a point not far above the great epiglacial lakes in southern Norway.

But the melting of the inland ice did not go on uninterruptedly. When the land had risen more than half the post-glacial uplift, and when, presumably, the ice was more than half gone, a new deterioration of the climate commenced. It is possible it did not get worse than the present, but it was enough to stop the melting of the inland ice, which again arose above the snow line. The ice again assumed the character of a living glacier, and kept its position unaltered for a long time. Under the pressure of this constant ice load the land again was kept at a constant level. We find, especially in northern Norway, a new strand-linje (sea beach), occurring at about 40 per cent. of the epiglacial and great terraces, built up with a fauna quite like the modern. This new marked phase in postglacial time I have called *the sub-glacial period*, denoting its half glacial condition. In Sweden this epoch is also marked by a very distinct beach line, but in Scania and Gothland this low raised beach in places is built upon peat, which shows that the uplift of land in the Boreal period did exceed that in the following. For this reason, the Swedish geologists speak of the *post-glacial depression*. The term post-glacial for this general phase is very unfortunate. It must necessarily literally denote all the time after the deuteroglacial-epiglacial period, for which time we have no other name. And as the constant level in Norway only represents a single phase in the

general post-glacial upheaval, and as the depression in southern Sweden may be a quite local, peripheric phenomenon attached to the Baltic, I must insist upon the more significant, yet neutral, form *subglacial* period for the age of the lower beach line.

The inland ice was then, as explained, reduced to a zone (about 50 kilometers broad) across the middle of the eastern valleys. This fact must have a curious consequence in the fact that these valleys must have been dammed up by the ice and filled with lakes whose outlets ran west and north through the gaps in the watershed. These glacial lakes have actually left very distinct marks in the greatest eastern valleys in Norway, Gudbrandsdal and Oesterdal. We not only find in their upper tracts enormous terraces of material brought by the glacier from the south, terraces without any parallel on the other side of the watershed, but we also find here very fine beach lines—*seter*—partially cut in the rock, corresponding in height with the terraces and with the draining gaps, 620^m, 660^m respectively—quite like the famous Parallel roads of Lochaber, but very much more extensive. From these ice-dammed subglacial lakes there flowed great rivers across the present watershed filling up with their heavy sediment many of the epiglacial lakes on the northwestern coast, and building great subglacial clay terraces at the level of the lower ancient sea beach.

The erosion of the marginal glaciers has set its mark also in the subglacial time in some inland lakes as Storsjö and Sensjö, in Oesterdalen, Mösvatn and Totak, in Telemarken which have their greatest depth in the upper part and terminal moraines at the present upper end of the lakes.

So far as I can see the subglacial period also prevailed in North America, without receiving yet, however, due attention from glacial students. I cannot here deal with all the raised beaches in the east formed by the sea and by the lakes which naturally can be referred to this period, but I shall use the occasion to point out that the apparently insoluble difficulty in harmonizing archeological and biological facts with the geological data connected with the ancient "Quaternary" lakes in the Great Basin

will immediately vanish when the two great humid periods are regarded not as proteroglacial and as deuteroglacial, but as deuteroglacial and subglacial or—what I think is more probable—as correlate with the two Norwegian post-glacial warm periods (before and after the subglacial), the climatic changes caused by a shifting of the pole westwards, which alone is able to account for the late glaciation of the Cordilleras in Atlantic post-glacial.

At last also the subglacial remainder of the inland ice commenced to melt away in the warm subboreal period. The country rose farther above the sea, and finally, by some intermediate steps, attained its present position. The modern sea beach shows everywhere so great a development, and is so sharply built, that all alleged displacement in historical times must be received with the greatest distrust. We have, notwithstanding all such relations, full reason to maintain that the seashore since the ice left has remained practically unchanged, as also the climate in historical time. We have reached the constant *recent period* in the most rigorous sense, and therewith conclude our synopsis of the Quaternary history of Norway.

There is, however, yet a problem of capital interest, which I cannot quite pass even in this short account. It is the question, When did *man* appear in geological history? The evidence given in Norway is, however, not very direct. We have seen that all traces of preglacial life were swept away, except the littoral find at great depth at Storeggen. We have also seen that the traces of interglacial life are very doubtful, and that we were obliged to go to Denmark to get better information about interglacial time. We have found that the Arctic flora here (with the reindeer) which flourished upon the proteroglacial bottom moraine, was superseded by the aspen vegetation (with elk) when the reindeer had already disappeared (J. Steenstrup). Now we know that in central Europe paleolithic man was contemporaneous with the reindeer, which will date this reindeer period back to the close of the proteroglacial time, and probably yet higher up. But in Denmark, it is only with the next vegetation, with *Pinus sylvestris*, that the first traces of man

appear, represented by the well-known refuse heaps, the *kökken möddinger*, where, with shells and bones of *Bos primigenius* and *Alca impennis*, are found many rude instruments of horn, bone, or stone. This culture, which did not know any other domesticated animal than the dog, is by some archeologists called mesolithic. *Kökken möddinger* and implements of the same type, *the coast finds*, are only discovered in non-deuteroglaciated places of Denmark and Sweden, which fact alone goes far to prove the assumption that the *Pinus sylvestris* period really is interglacial, as I have advocated above. And the molluscs in the refuse heaps on the northern shores of the Danish isles are quite the same as in the (upper) *Cyprina*-clay on the southern shores, which overlies the proteroglacial moraine, and is here generally ploughed out by the rather feeble margin of the deuteroglacial Baltic ice tongue. This interglacial layer contains often a stratum with fresh water molluscs and in this supramarine deposit there was found in Langeland shells of *Cardium edule* and *Nassa reticulata*, in which I cannot but see a rudimentary *kökken mödding* and a proof for the interglacial age of this mesolithic culture.

From Norway we have only a few finds of implements of this type, as might be expected, because the habitable coast was so greatly depressed and covered in the following deuteroglacial period. But it is reasonable to suppose that it also was inhabited by a population akin to the Danish. When the latest ice sheet pushed forward to the great mostly-submarine terminal moraine, the retreat of this population on the western foreland was intercepted, and interglacial man was obliged to adjust his mode of life somehow to Esquimau fashion. But there is no reason to think him quite exterminated here on the shore of the life-giving Atlantic. And anthropologic studies have indeed proved that on the western margin, just so far east as the deuteroglacial ice left land outside, there lives yet a brachycephalic population, while everywhere else (even in the innermost western fjords) dolichocephals and mesocephals are in great majority. This distribution of anthropological types is quite unaccountable by any other supposition than that the brachycephals are descend-

ants of the interglacial Norwegians and that the whole deutero-glaciated country was peopled by Aryan dolichocephals in early post-glacial, boreal time. We know that these new immigrants had at least four domesticated animals, and were in possession of the art of grinding their stone implements. Can we now date the appearance of *neolithic man* by more direct geological means? There are found so many flint implements in such depth in probable subglacial terraces in Norway that it may be taken for granted that the country was populated, however sparsely, up to and beyond the polar circle in subglacial time. In Sweden polished implements have been discovered in the peat layers below the subglacial beach, so it will perhaps be reasonable to refer the first appearance of neolithic man also on geological dates to the genial Boreal period between epiglacial and sub-glacial time. Approaching our own culture, we find that the country in the *bronze age* was still depressed. In Smålenene, to the east of Kristianiafjord, are observed about 150 rock sculptures from the bronze age which are situated at about 22 to 25 meters above the sea; none at lower levels. As these sculptures almost always are made along a shore, we are justified in supposing that more than ten per cent. of the land yet was unfinished in early bronze age. From early *iron age* we have barrows quite near the present constant sea level, so we may assume that the recent geological period coincides with the iron age and historical time.

If the theory of ice depression is correct, there must, even in the bronze age, have existed a remnant of the inland ice, which, as explained before, must be sought for across the middle of eastern valleys. In this zone we could not expect to find implements from the stone age or bronze age. There has as yet been found only four stone hatchets in all the districts near the former ice shed, against many hundred stone implements in the districts on both sides of the same valleys, and these perforated hatchets have been in use far down in metallic time.

The ice zone must have stopped the immigration as the inland ice of Greenland does now. This is the reason together with the

depression of the coast land why neolithic man did not go farther up in Sweden than 61° northeast, while the Norwegian coast was free all along, and permitted his advance up to 70°. Another consequence is that the northern part of the long valleys in southeastern Norway must get its first population from the west coast. This is also proved to be the case, not only by the existence of a well-marked anthropological boundary across these continuous valleys, but also by a singular contrast in dialects and traditions. Reversedly, this signifies that the present Scandinavian race really was the first post-glacial occupant of the country. In the administrative divisions we find traces of the old ice barrier as far down as only a century ago. It is thus possible to follow the effect of the ancient land ice in Norway down to our own day.

In closing this hasty summary of the Quaternary history of Norway I cannot quite omit the doubtful question about the absolute chronology. We have seen that in the bronze age which the archeologists are able to date in Scandinavia from 1700 to 500 B.C., more than ten per cent. of the post-glacial upheaval was not yet accomplished. As the upheaval has not been uninterrupted, we cannot directly conclude that the whole elevation has had a duration of about 30,000 years. The long time from early iron age in which the shore line has been constant enters into our standard. But we can draw a more reliable comparison between the terraces from the different periods, when we take the greater eroding power of the old inland ice and its greater glaciers in due consideration. I cannot here specify my calculations, but will say that I regard myself as on the safe side when I compute the time for forming the subglacial terraces and beaches to not more than double the last constant period, which may be reckoned at 2,000 years. For these two constant post-glacial periods together we thus get about 5,000 to 6,000 years. The relatively small terrace deposits from the remainder of post-glacial time cannot by any means give more than half this value. We may, therefore, on this, as I think, very reliable estimate, calculate the whole post-glacial time to be 7,000 to 9,000 years. To about the same numbers

I have come by calculating from the mean depth of neolithic finds in Norwegian peats, but this computation has not quite so much importance, though the fact that the generally adopted archeological chronology agrees as well with geological estimates certainly has some weight.

I shall recall the fact that calculations on the length of post-glacial time based on the receding Niagara, St. Anthony Falls, or the Michigan lake shore, on boulder pedestals in Scotland, the denudation of the Somme, the Plum creek, or the Raccoon valley, deposition of the Tinière or the Rhone, etc., delta, the thickness of glacial clay in New Hampshire and in Sweden, the rate of growth of peat in North America and Ireland, the atmospheric waste of the Parallel roads in Lochaber, the depth of some ancient neolithic finds, that all these give numbers of about the same value, 5,000 to 12,000 years. Doubtful as some of these chronometers may be, all fair chances are against any supposition which differs in any considerable degree from those of about *thirty independent* estimates I have got together. With full regard to a legitimate calculation of probabilities, it may be predicated that the number of 7,000 to 10,000 years is as nearly an exact estimate of the *duration of post-glacial time* as can ever be expected.

It is now tempting to try a comparison between the subglacial and the epiglacial terraces and lakes in Norway. When the much greater eroding force of the epiglacial glaciers is properly reduced, I do not think it can be very much at variance with the truth to compute the epiglacial period to be between five and ten times the duration of the subglacial, the smaller number being somewhat more probable. We would then get *10,000 to 20,000 years for the epiglacial period and perhaps 15,000 to 25,000 for the whole deuteroglacial time*. For the *interglacial period*, the Norwegian geology cannot as yet give any reliable measure but the depth of the aspen and pine layers in the Danish peats as compared with the post-glacial oak and birch layers does answer very well to the American estimates of one and one-half to two times the duration of post-glacial time—let us take about 15,000 years. We may next compare the proteroglacial fjords with the epiglacial lakes

and may by these means get some idea as to the length of the first great ice age. The farther we go from our own time the more wholly conjectural will our numbers become, of course. But as other more reliable measures as yet are wanting, I shall venture a first approximation, calculating the time in which the enormous proteroglacial marginal glaciers eroded our fjords, as five to ten times the epiglacial time in which our great epiglacial lakes were scooped out—the higher estimate in this case being somewhat more probable. This would perhaps make *100,000 to 150,000 years for the whole proteroglacial period*, *i. e.*, about five times the duration of the deuteroglacial time—a relation which, as far as I see, is in very good accordance with the general quantitative difference between the effects of the first and second great glaciations. This will give for the whole Quaternary-post-tertiary time about 140,000–200,000 years.

I see very well how precarious such computations may seem, especially as I here cannot give the detailed calculations—but I do not think it possible that any of these have given numbers five times too great or small. Under these circumstances they must be taken for a very good geological approximation. By getting parallel estimates from other glaciated countries, it will appear, I think, that we will have, on wholly geological ground, more positive and reliable data for the Quaternary chronology, than those derived from astronomical speculations.

I add for greater ease in comparison my reading of the Quaternary history of Norway in a tabular form.

ANDR. M. HANSEN.

SYNOPSIS OF QUATERNARY HISTORY OF NORWAY.

Period.	Epoch.	Ice Sheet.	Elevation of Land.	Erosion.	Deposits.	Temperature.	Fauna and Flora.	Man.	Probable Duration (1000 yrs).
Protero-glacial.	1. 2.	1. Grows to the ocean slope. 2. Terminal glaciers in the fiords, eastern margin near Petschora.	Sinks from 2-400 M. above the present to about the present (?)	1 & 2. Norwegian channel. 2. The great fiords.	Undermost bottom moraine on continental side. Terrace plain sub-marine around the west coast.	Sinking from the warmer Pleistocene to 8-10° C. below the present mean.	Arctic.	No traces.	100–150
Interglacial.	1. 2. 3.	None (?)	The present (?)	The present forces.	Intermediate sand layers at Jaederen(?)	At times warmer than now.	1. { Reindeer Dryas 2. { Elk. Populus trem. 3. { Bos primig. Pinus sylv.	3. Danish kökken möddinger. Western brachyceph. in Norway.	15–20
Deutero-glacial.	1. Ra-Epoch.	1. Grows to the fiord heads, terminal moraine Baltic tongue.	1. Sinking to about 250 M. below the present near the ice centre.	1 Ra-lakes and intermediate lakes behind moraines.	1. Terminal moraine. Upper diluvium round the Baltic.	2.5-5° C. lower than the present.		?	15-25.
	2. Epi-glacial.	2. Terminal glaciers in the lakes behind the fiord heads.	2. Upper ancient beach.	2. Great lakes near the fiords. Gaps at the watershed. Sack valleys.	2. High marine terraces.		2. Arctic (Leda clay).		2. 10-20.
Postglacial.	1. Boreal.	1. Melting rapidly.	1. Rising rapidly.	1. Rivercuts in epiglacial terraces.	1. Small terraces.	1. About 3° C. warmer.	1. Boreal (oak, ash).	1. Neolithic immigration.	7-9.
	2. Sub-glacial.	2. Gone except across the eastern valleys.	2. At the lower (40 pct.) ancient beach.	2. Lakes in central Norway. Seter.	2. Terraces at 40 pct.; inland terraces.	2. As now.	2. As now.	2. Neolithic man.	2. 2-3
	3. Sub-boreal.	3. Melting away.	3. Rising to the present.	3. As now.	3. Small terraces.	3. Somewhat higher.	3. Some southern forms. Pine in the peats.	3. Bronze age at 10 pct. of the upheaval.	
	4. Recent.	4. Gone.	4. The present.	4. The present.	4. The present.	4. The present.	4. The present.	4. Iron age, historical time.	4. 2.

NAES. HEDEM. AUGUST, 1893.

ANDR M. HANSEN.

DUAL NOMENCLATURE IN GEOLOGICAL CLASSIFICATION.[1]

At the meeting of the American Association for the Advancement of Science, at Rochester, in 1892, while discussing a paper of Professor James Hall, read by Mr. Merrill, on the classification of the Devonian rocks in eastern New York, I ventured to express the opinion that the time was ripe for the recognition of the duality of the group of facts which geologists attempt to classify in what we call the geological column or scale of formations.

Since that meeting, Mr. Darton has published a paper[2] restating and commenting upon substantially the same facts reported by Hall and proposing a special use of the name Catskill. Still later papers have appeared by Professors Stephenson[3] and Prosser[4] discussing the proposition made by Mr. Darton, the one from the stratigraphical, the other from the paleontological point of view. There is also now going on the preparation of a revised geological map of New York state, containing the typical paleozoic section for North America. These and other reasons have led me to think it not inopportune to ask the serious attention of geologists to the adoption of a dual method of nomenclature in the classification of the facts of historical geology.

There is nothing novel in the proposition that there are both stratigraphical and chronological divisions in the geological classification, but it is only recently that practical geologists

[1] Presented to the Geological Society at its meeting in Boston, December, 1893.

[2] Oneonta and Chemung formation in Eastern Central New York. Am. Jour. Sci., III., Vol. XLV., p. 203.

[3] J. J. Stevenson: On the Use of the Name Catskill, Am. Jour. Sci. III., XLVI., 330.

[4] C. S. Prosser: The Upper Hamilton and Portage Stages of Central and Eastern New York, Am. Jour. Sci., III., XLVI., p. 212.

have seen the importance of classifying *terranes* and *periods* separately.

James D. Dana,[1] in 1855, set forth, with great clearness, the importance of the chronological classification of rocks, and in his manual[2] all geologists have been made familiar with the meaning of a chronological classification of stratified rocks, but the classification is a classification of rock strata, and the time-divisions are those determined by the strata, so that but one nomenclature has been needed or used.

The International Congress of Geologists was the first to distinctly formulate a dual method of classification, but here, too, it was only two ways of classifying one set of facts that was proposed. The divisions of the scale have been identical and in the terms of strata. The Congress was organized for the purpose of unifying nomenclature, but one of the most important results of the Congress has been the discovery that uniformity, in the sense first proposed, is not practicable.

In advocating a dual nomenclature, I would carry the differentiation one step farther, and propose that we give a different nomenclature to the time-scale, and classify it independently from the terrane-scale, because the fossils by which its divisions are determined contain, in themselves, the evidence of their time relations. In an article in THE JOURNAL OF GEOLOGY[3] I described the history of the elaboration of the system of nomenclature and classification now in use, and showed how the geological formation is the actual unit of classification in the present system. Having called attention to the fact that the geological formation and the geological period have become thoroughly differentiated, I remarked in closing that "the elaborating further and making more precise the geological time-scale must come from a direct study of the life history of organisms as

[1] See Proceedings of the American Association for the Advancement of Science for 1855; also On American Geological History, Am. Jour. Sci., II., Vol. XXII., pp. 335-344.

[2] DANA: Manual of Geology, 1st edition 1863, 2d edition 1874, 3d edition 1879.

[3] The Making of the Geological Time-Scale. JOUR. OF GEOL., Vol. I., pp. 180-196. See also Elements of the Geological Time-Scale, Vol. I., pp. 283-295, 1893.

recorded in the stratigraphical formations" (p. 197). It is the carrying out of this thought which requires the adoption of a dual nomenclature in the classification.

Perhaps the best thing that can be said in favor of such a proposition is, that it will enable us to record the facts of our science with greater precision, accuracy, and truthfulness; and nothing worse, I think, can be said against it than that it will cause confusion and difficulty in mapping and in the estimating of the relations and values of the old terms and system of classification, this simply because it is not the old system. Evolution has worked the same difficulty in the classifying of organisms, because it has suggested that species are changing and not fixed quantities, and in the early part of this century the principle of identification of rocks by their fossils upset, in a similar way, the elaborate classification of the Wernerian school based upon the supposed natural sequence of particular kinds of rocks.

Where new geology is being elaborated, the application of the dual method may be easily attained, and the adoption of the method by the United States Geological Survey has therefore been found possible and practicable. But the greatest difficulty, and hence the real retardation of progress, is found in applying the method where standards have been established and used on the old basis. The New York rocks constitute, for North America, the standard section of Paleozoic geology. They were classified on the basis of unity and integrity of geological formations.

By unity, I refer to the notion that a geological formation is an integral unit in the single geological stratigraphical column, which may be identified in distinct geographical regions by its fossils; and by integrity, I mean the notion that a formation is the same in its position in this column, wherever found, thickening and thinning, and even changing somewhat in the character of its material from place to place, but always the same in its relation to other formations.

Therefore, in discussing geology in North America, it has become a practice to use such terms as Oriskany, or Niagara, or

Potsdam as names of geological divisions of the scale of which there are a definite number. These arranged in a definite order, according to English sequence of systems: Cambrian, Silurian, Devonian, and Carboniferous, etc., constitute *the* standard geological scale.

These formations have also been called Epochs and Periods, and because the succession of time is continuous, the strict application of the method has required the filling of the whole interval, from the Cambrian to the Carboniferous, by these formations, except when unconformity gives marked evidence of break in the record. The old system requires that in all the sections, the lines separating the formations from one another shall coincide with the stratigraphical divisions, and progress has been checked by the authoritative rebuke, from those who are supposed to know, of any timid suggestion that the geology of a newly discovered section does not conform to the standard. We are already familiar with the proposition that there are such systems, groups and formations, on the one hand, and Ages, Periods and Epochs, on the other, but our whole nomenclature and classification is applied and used as if the divisions indicated by the two categories were strictly synonymous; in fact, the nomenclature of the International Congress went no farther than to propose that the names of the divisions of the one category, viz.: *group*, *system*, *series*, *stage*, should be applied to the same concrete geological facts as the corresponding names of the other category, *era*, *period*, *epoch*, *age*, and that these names of the categories should be universally used; as if, a century ago, zoölogists had proposed that class, order, family, genus, be used in a uniform manner by all naturalists. It is the essential idea contained in this differentiation of nomenclature, in two directions, which I would here emphasize and elaborate.

When geologists consider the two scales, the time-scale and the formation-scale, it is found that the divisions are not synonymous, but that there are two distinct sets of facts confused in our present nomenclature and classification. There is a geological time-scale, and, however we subdivide it, or however we

mark or distinguish the divisions one from another, as a scale it is one and continuous, the parts or divisions of the scale come up to each other and are in a regular succession, but they cannot, from the nature of the scale itself, overlap or duplicate each other. Uniformity in nomenclature, and definite well-known standards and limits, and accepted means of recognizing each division for universal use, are essential to the perfection of this time-scale. In all geological literature only one name should be applied to each subdivision of the time scale, and there should be recognized for each of the grander divisions a prime standard, in some particular place on the earth, whose marks may be examined with closer and more minute discrimination as the science develops in precision. Further, in each continent we need separate standards which shall be compared as accurately as possible with the prime standard, so that each continent may have its typical geological time-scale, in concrete form, with which local formations may be corrected.

The above applies, however, only to the time-scale; the list of geological formations is a totally different thing; there is no universal uniformity of geological formations; to attempt to apply a single set of names to them is always more or less to cramp and distort the facts. Geological formations are local affairs, and to restrict geological classification to a single formation scale is to hide-bind the progress of science. There may be as many formation scales as there are examined sections of stratified rocks, and we know that all the marks by which a formation may be defined constantly vary, so that the definition of a formation, small or great, is not alike for any ten miles of its extent, and often ten feet of extension will show clear marks of difference.

Thus we see that there are two distinct sets of facts with which the geologist has to deal, and the United States Geological Survey has clearly recognized this truth in giving rules for the definition and naming of geological formations, independent of time relations, which are left for the more deliberate determination of the paleontologists. It is not, however, in the new work so much as in the revision of old standards that the appli-

cation of the dual system of nomenclature needs to be insisted upon. And when the occasion for revision of an accepted standard, such as the geology of New York state, appears, it is more important to adapt the classification to the needs of the coming century than to preserve the imperfections of the one now closing. It was a bold step when, over fifty years ago, the New York state geologists, Emmons, Mather, Vanuxem and Hall, discarded the then standard Wernerian classification to which McClure and Eaton had, with great pains, adjusted our American geology, and, describing the New York rocks just as they found them, with new names and a new classification, formed the New York system. This New York system has become the standard formation-scale for American geology.

But since the New York system was described, the fossils, which were then looked upon as mere marks by which to identify the formations, have come to be known as the evidences of the gradual evolution of species, each one holding its definite place in a continuous history of organism. As stratigraphy replaced the Wernerian lithology in classifying formations in 1840, so now paleontology comes forward to take the place of stratigraphy as the true means of classifying geological periods.

The case of the Catskill formation is in point. It has been a recognized fact, since the New York State Survey Reports were published, that the Catskill formation of New York was peculiar to the eastern parts of the state, and that it thins out on passing westward, and that the Chemung formation is well developed in western New York, and becomes insignificant or is wanting in the east. According to the single method of geological classification, it is necessary to call one above or below the other, and in our geological columns we have been accustomed to see the Catskill as the upper member of the Devonian lying above the Chemung, and because usage has vacillated between the time-scale and the formation-scale the confusion has been very difficult to formulate, or to bring to the minds of geologists.

If we are discussing the formation-scale, it is true to the facts to speak of the Catskill formation as lying above the Che-

mung formation, except that it does not express all the truth or the exact truth, for when the Catskill deposits are found in relation to the Chemung deposits in a continuous section, some Catskill facies of sedimentation do succeed the marine Chemung, but it may not all succeed all the Chemung, as the testimony of numerous observers in Pennsylvania and further south shows.

When, however, we are talking of the time-scale the confusion is more apparent; for it is clear that one period cannot both precede and follow a second period. Either the Catskill Period must follow the Chemung, or the Chemung must follow the Catskill, or else they are synonymous terms, and one is superfluous. When Mr. Darton proposes that Catskill be used in place of Chemung, he is reasonable on the old basis of the old method of classification, but the facts are not thus elucidated. The facts are that the Chemung period is synchronous with a part of the Catskill period, but that the Catskill formation is distinct from the Chemung formation, and when they occupy the same section the Catskill formation succeeds the Chemung.

Those who have watched the discussion of the classification of the Upper Devonian, will remember that one of the greatest difficulties presented in the progress of field studies has been the fact that collectors have so frequently reported fossils where they ought not to be. Formations, classified as Catskill in the books, have yielded Chemung fossils, or, above so-called Catskill rocks, Chemung fossils have appeared, or above Hamilton rocks, in rocks regarded as Portage, have been found Hamilton fossils again. Geologists on the Pennsylvania Survey have met with serious rebuke for proposing Chemung-Catskill and similar names which have thrown discredit upon the integrity of the formations. These discrepancies have been interpreted to be evidence that the observers could not tell the two formations apart, or had been mistaken in their observations; but the true interpretation is that the criteria for determining the divisions of the time-scale have disagreed with the criteria of the formation-scale. The latest phase of the discussion has appeared in the papers of Stevenson, Darton and Prosser, before cited.

In the discussion of Professor Hall's paper at the Rochester meeting, the question came definitely before us as to the relative value of fossils and structure as means of determining or tracing equivalency of age of formations. In that discussion I maintained that fossils are always the only certain means of carrying from one geological basin to another the evidence of time-relations of the deposits, that structure was indicative of equivalency only when actual continuity of a formation can be traced. Both of Mr. Stevenson's [1] papers recognize the physical features of the formation to be of great importance in determining its position in the time-scale, and in his use of terms he appears to be classifying formations and yet using the language of the time-scale. In his presidential address he maintained, as quoted by himself, that the series of beds included within the Catskill and Chemung Periods should be grouped into one period, the Chemung, with three epochs, the Portage, the Chemung and the Catskill (page 320), and in his paper in 1893, he insists that the Chemung, and not the Catskill, is the epoch whose name should be applied to designate the whole group, while Catskill must be retained in its original signification only.

Mr. Darton, on the other hand, is discussing the formation-scale alone. The principal purpose of his investigation is said to be to determine the relations and distribution of the Oneonta and Chemung formations (p. 203). In the passage on the status of the name "Catskill" the author proposes to discontinue the use of Catskill as a coördinate formation term, and use the term "Catskill group," to include the Portage and Chemung formations (p. 209). He maintains, correctly, I think, that the term Catskill has been applied in the past to beds of a certain lithologic character—the hard sandstones and red shales—and it has had no definite stratigraphic significance. The rocks of the Catskill Mountains and westward have no distinctive fauna of stratigraphic significance, and they cannot be correlated on paleontologic grounds (p. 208).

[1] The Chemung and Catskill (Upper Devonian on the Eastern Side of the Appalachian basin). A. A. A. S., Vol. 42.

On the use of the name Catskill. Am. Jour. Sci., Vol. XLVI., p. 330.

On the assumption, which has been the common practice up to the present time, that the divisions of the time-scale and of the list of formations are synonymous, it is reasonable to insist that the Catskill and the Chemung are not correlative terms, and that, in case we apply them as formation names, the one must succeed the other, but I think we all know that this is not the case. We know, that is, that in western New York a continuous section takes us through Hamilton, Portage, Chemung, Conglomerate and Carboniferous formations;[1] that a like section in the meridian of Cayuga Lake takes us through Hamilton, an interval filled with *Spirifer levis* beds, the Ithaca group and 600 feet with Portage fauna, then the Chemung, the Catskill, and finally the Carboniferous. Farther east the interval between the Hamilton and Chemung is filled by rocks with an advanced stage of the Hamilton fauna; then the Oneonta and next rocks with another stage of the Hamilton fauna, then the Chemung and the Catskill. Still farther east, Chemung drops out from the series; and if we go on to Maine and Eastern New Brunswick, the Hamilton also falls out, and a long series with the latest marine fauna an Eodevonian Oriskany fauna, separated from the Carboniferous deposits by several thousand feet of deposits which, faunally and structurally, may be considered equivalent to the Catskill of New York. It is evident, thus, that at different localities the Catskill formation has a time value in one place equivalent to the closing part of the Chemung formation; at another place to the whole of the Chemung; at another to the upper part of the Chemung, and also an earlier stage during the formations of the Ithaca formation; at another place it represents the whole upper Devonian, and, if we mean to extend the use of the name to Maine, to the whole of the upper, middle, and most of the lower Devonian.

It is, therefore, clearly inappropriate to use the term Catskill as a name in the time-scale, because it has no common definition in that scale. It is an appropriate local formation name for deposits succeeding Hamilton or Chemung formations in Eastern

[1] See the table on p. 155.

New York and farther southwest. It should not be applied to cover the three divisions of the Upper Devonian, because as a time indicator it is inappropriate, as just stated; and as a formation name it has already a use, and should not be used in two senses; and, thirdly, even if used in the more comprehensive sense, it is inapplicable because the Portage and Chemung are not represented, at least only imperfectly, in the geological area named Catskill.

The Catskill is a distinct and well defined geological formation, but it is not a period or an epoch, nor does it represent any particular period of geological time. The classification of the Upper Devonian deposits is a very difficult matter when it is attempted to make a continuous series of the formations of New York alone. As I have previously shown, the succession of faunas in the sections of New York rocks at distances of not over fifty miles apart make plain this fact. At the Cayuga lake meridian, the section is Hamilton, terminating with Tully limestone and Genesee shale, then the Ithaca group, which has first a Portage fauna, then the Ithaca fauna, third, the Portage fauna again, and finally Chemung capped by Catskill and Carboniferous. A little further east of the Chenango valley, it is Hamilton; then a fauna intermediate between Hamilton and Ithaca (but no Tully or Genesee); then the Oneonta, a brackish and fresh water fauna; then the late Ithaca fauna, still with Hamilton types in it; no Portage fauna, but Chemung fauna following the upper Ithaca fauna.[1]

In this faunal succession there is a clear indication of the age of the Oneonta sandstones. It is clearly in the midst of the rocks characterized by the Ithaca fauna. As I have shown in the paper referred to,[2] the marine Brachiopod faunas occupying the place between the Hamilton and the Chemung faunas in Central New York, of which the Ithaca is the best known, are modified successors of the Hamilton, or Mesodevonian fauna, and the Oneonta group, with its fresh and brackish water fauna is in the

[1] WILLIAMS: The Classification of the Upper Devonian. Proc. Am. Assoc. Adv. Sci., Vol. XXXIV., p. 225, 1886.

[2] Proc. A. A. A. S., XXXIV., 1885, pp. 222-3.

midst of it; that is, the Ithaca fauna is both below and above it. Again, upon going further west, the same interval is filled by a non-brachiopod marine fauna, *i. e.*, that of the typical Portage group of Genesee valley, and the Ithaca group of Ithaca is in the midst of the corresponding rocks of the Portage, as the Oneonta is in the midst of the Ithaca. This I interpreted, in the paper referred to, as indicating that the succession of faunas was controlled by oscillation of levels during the accumulation of the deposits, the eastern shores rising during the first half of the Portage (of the Genesee valley series) so that, during the particular stage represented by the fossiliferous zone of the Ithaca group, Portage fossils were being accumulated in the Genesee valley sediments, Ithaca fauna at Cayuga lake meridian, and, from Chenango eastward to Oneonta, sands with fresh water Amnigenia and Holoptychius characteristic of the Catskill formation.

THE FORMATIONS OF THE DEVONIAN SYSTEM IN THE APPALACHIAN REGION AND THEIR RELATIONS TO THE TIME-SCALE.

Time Scale.	Formation Scale.				
	GENESEE RIVER.	CAYUGA LAKE.	DELAWARE CO.	HUDSON RIVER.	MAINE.
Eocarboniferous	....	......	......	......	......
Neodevonian..........	Conglomerate Chemung Portage Genesee	Catskill Chemung P^2 Ithaca P^1 Genesee Tully	Catskill Chemung H Oneonta H^2	Catskill H^2	Catskill
Mesodevonian........	Hamilton Marcellus	Hamilton Marcellus	Hamilton	Hamilton	
Eodevonian	Corniferous Oriskany	Corniferous Onondaga Oriskany	Onondaga Schoharie Caudagalli Oriskany	Schoharie Caudagalli Oriskany	Oriskany
Neosilurian............	....	......	......	......	......

The table on page 155 presents the facts regarding these formations, and what I conceive to be the chief difficulties in attempting to use a single nomenclature and classification. The question at once arises how will a dual nomenclature help us over these difficulties.

On the left I have placed a part of the time-scale adjusting the formation-scales for the several sections, approximately as I think the fossils indicate their time relations to have been.

Formations may be described for a particular geological section with precision as to kind of rock, stratigraphical sequence and thickness, and, as we compare one section with another, we are obliged to become more indefinite in our description and speak in generalities, or averages ; and therefore the wider we extend the use of a formation name, the less accurate and the more indefinite does it become.

On the contrary, in the distinguishing of time-relations or position in the time-scale, the individual facts, the local handful of fossils are the more indefinite, indicating only, it may be, Paleozoic or Mesozoic age. The extension of the comparison to the study of fossils above and below, and to the comparison of fossils in adjoining sections, and to their geographical distribution for a wide extent, increases the precision in locating position in the geological time scale.

It happens, therefore, that, while formation definitions are best constructed in the field in the presence of the actual rock section, the time definition becomes more accurate the more thorough the investigation of the fossils is made. Hence in constructing a time-scale, it begins properly with the grander divisions, and it is built up and perfected by subdivision, whereas the formation-scales begin with the lesser strata and are elaborated and completed by adding together successive strata.

The grander divisions of the time-scale are already in use. These are universally known as the Paleozoic, the Mesozoic, and the Cenozoic. The primary sub-divisions of these geological *times* are also very widely understood and used. They may be called *eras*, and are named Cambrian, Ordovician, Silurian, Devo-

nian, Carboniferous (constituting the eras of Paleozoic time), Triassic, Jurassic, and Cretaceous (the eras of Mesozoic time), and Eocene, Neocene, and Recent (the eras of Cenozoic time). Each of these eras is known, not by the formations which represent it, but by the fossils which characterize it. Proceeding in the same manner, I would propose that we subdivide the eras into Periods, according to the lines which paleontologists have generally come to recognize as convenient and natural, making a three-fold (or in some cases a two-fold division) of each era, and that they be distinguished by prefixing the syllables *Eo*, *Meso* and *Neo*, to the name of the era, thus : the *Eocambrian*, or the period of the Olenellus fauna, the *Mesocambrian*, or the period of the Paradoxides fauna, the *Neocambrian*, or the period of the Dikellocephalus fauna, and in the Devonian, the *Eodevonian*, *Mesodevonian*, and *Neodevonian*, and in the same manner for each of the other eras.

Although attempts have been made to make finer divisions of the time-scale, into *Epochs* and, lately, into *Hemeræ*,[1] it is doubtful whether our knowledge of the history of organisms is sufficiently advanced to enable paleontologists to define the fauna of an *epoch* so that it can be made use of for more than a thousand miles of geographical extent, and the *hemeræ* of single species cannot be considered as precisely alike in two distinct geological provinces.

In the application of this time-scale to any particular case the degree of minuteness of definition will depend upon the knowledge we have of the time relations of the contained fossils. In the case in hand, the fauna of the Catskill is not sufficiently definitive in itself to enable us to be more precise than to assign it to the Devonian Era. This is affirmed by the fact that, in England, the old Red Sandstone is known not as a part of, but as the representative of the whole Devonian. If we attempt to define the age of the Catskill formation by faunas immediately preceding or succeeding it, the definition in time is equally indistinct, because

[1] S. S. Buckman : The Bajocian of the Sherborne Districts, its Relation to Subjacent and Superjacent Strata. Q. J. G. S., Vol. XLIX., p. 479–522, Nov., 1893.

not alike for different sections which are geographically not greatly separated from each other.

The Catskill formation is primarily a local formation exhibited in the Catskill mountain region of New York, distinguished physically as a series of sandstones and shales with greater or less red-color, and by the absence of marine fossils, and the occasional presence of shells and fish believed to have been of fresh or brackish water habitats. It is the local expression of the broadening shore condition of the continental elevation which brought in the coal-making, or Carboniferous age of eastern North America. As a *formation*, it is separated from what went before by the reddening, or graying of the sandstones and shales, their coarser, more irregular structure, the departure of marine organisms, and the occasional appearance of brackish water shells, fishes, and some fossil drift-wood and plants. In relation to the *time* scale, the period of beginning of this formation varies with the regions in which it is exposed. At its extreme eastern extension, on the peninsula of Gaspe, and in eastern New England, it began in the Eodevonian Period. Along the Hudson River, it began at the beginning of the Neodevonian, or perhaps before the termination of the Mesodevonian. In the region of Oneonta and westward it began soon after the beginning of the Neodevonian Period, and then withdrew eastward, the marine conditions returning over the region leaving the Oneonta formation as its record, and later in the middle of the Neodevonian, it returned and continued on to the close of the Devonian era. In the region of Bradford County, Pennsylvania, it did not begin to be deposited till near the close of the Neodevonian Period. Farther west the Olean Conglomerate marks the final close of the Devonian Era, and the formation in question did not begin till after the close of the Devonian. In the eastern Pennsylvania and more southern sections, its age varies with the locality. In general, it is terminated above by indications of the presence of permanent land conditions, either massive beds of rounded pebbles or conglomerates, or thin beds of coal or carbonaceous shales, or, in the absence of actual change in formation, the line is arbitrarily set by the supposed tracing of

equivalency of stratigraphical position by the structure from some region in which such marks are evident.

The Pocono and the Mauch Chunk are, as formations, but the continuation of the Catskill formation upward and are of local value as formation-names, but of little or no value as elements of a time-scale.

Thus the Catskill may continue to appear in the list of formations of New York, and the Appalachian province, where it generally appears as a Neodevonian formation, but it is useless to define or to discuss its more exact position in the time-scale, because its own time-criteria range through the whole Devonian Era, and its relations to formations whose time-criteria are more exact is indefinite and inconstant.

If we grant the truth of the general principle here set forth, it is evident that the increase of formation names can be no more objectionable than the increase of the names of mountains; and that there is no more reason for applying the same name to two formations which are of the same age, but differ in position and structure, than there is in giving two names to mountain ridges of the same range. The classification of formations into groups or systems will depend upon considerations of geological structure, and only secondarily upon time considerations; and even in the latter case, only because the same general geological events have affected the sedimentation in a similar way for a wide extent geographically.

On the other hand, the time-scale will depend for its classification upon the fossils and not upon structure. Stratigraphical sequence, of course, is important in reading fossils, but only as in a sentence, or on a page, the sequence of the words is important.

An organic species, or a genus, or an order lived only during a particular period of time, and it is for this reason that the fossils have an intrinsic time-value, but a mineral, or a rock may have been formed under like conditions and present like characteristics at any period of geological time. I refer of course to clastic rocks, and those formed through processes of sedimentation.

Marine invertebrates for the Paleozoic, and later marine vertebrates constitute the most satisfactory means for discerning geologic age, because the oceans, in which they live, are of worldwide extent and inter-communication. They are distributed around the globe, and from pole to pole, so far as the adaptation to conditions of environment will permit. Hence, we find it to be a fact that, at every period of geological time, there are representatives in all regions of the globe of the same species, or of closely allied species such as to mark the close correlation of time of their living. While this is true, it must be borne in mind that correlation cannot be made by fossils to a finer degree of discrimination than the facts of specific integrity allow. The life-period of species is not uniform, and the wider the distribution, the longer is, as a rule, the range; so we find, in practice, that with the present knowledge of fossils it is rarely possible to discriminate age to a finer degree than that indicated by the periods, Eocambrian, Mesocambrian, and Neocambrian, or similar periods for the other eras. Within such general limits, time relations can be discriminated by the fossils alone, and the progress of science will enable us to recognize more minute divisions of time as we proceed.

On the other hand, formations, being local phenomena, are discriminated with greater precision locally, and the indefiniteness in application of formation names increases with the wideness of the territory covered. No classification of terranes can be of universal application, for no formation, or formation character, or criterion of determination, is of world-wide extent. The time divisions are more precisely defined the larger they are ; the formation divisions are more precisely defined the smaller they are, and progress of knowledge will extend the precision in opposite ways for the two scales.

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ORIGIN AND CLASSIFICATION OF THE GREENSANDS OF NEW JERSEY.[1]

CONTENTS.

INTRODUCTION.

DURING the past two years the writer has been carrying on investigations upon the Cretaceous and Tertiary formations of New Jersey under the joint auspices of the State and National Geological Surveys. A preliminary study of the whole area was followed by the mapping, with the aid of others,[2] of three United States Geological Survey atlas sheets in the northern portion of the district, and more recently by the critical examination of five type sections across the state. The results of the earlier investigations have just been published,[3] while the later work will appear in the next annual report of the State Geologist.

In an area which had received such full investigation by as competent a geologist as the late Professor Geo. H. Cook, for

[1] Read before the Geological Society of America, at Boston, December, 1893.

[2] The writer had associated with him as assistants Messrs. C. W. Coman, H. S. Gane and R. M. Bagg.

[3] Rept. of the State Geologist of N. J. for 1892, pp. 167–246.

so many years the head of the State Survey, it was deemed advisable to act with great deliberation before proposing any important changes in the classification. Accordingly the first report to the State Geologist was limited to the fewest possible alterations in the accepted names of the formations, and the work made to conform so far as it was possible with the earlier results of the State Survey. As the work has progressed the necessity of modifying the classification hitherto adopted has become apparent, and such changes are presented at this time. The use of lithologic terms for the formations in the earlier nomenclature will be in the future discarded for place names, the older terms being retained to designate their economic equivalents. Local terms have been adopted, care being taken to select such as would characteristically represent the formations. The names of rivers, hills, and towns, in the vicinity of which typical sections are found, have been generally employed. In this manner the results of the work in New Jersey are brought into conformity with methods generally adopted at the present time in other areas.

The work carried on during the past field season in portions of the area never before studied to any extent on account of the thick covering of recent deposits, reveals the fact that the divisions established chiefly from an examination in the extreme north, are remarkably persistent. This knowledge has been gained to a large extent from recent well openings and borings made at frequent intervals by the writer and his assistants. The unconsolidated character of the sediments render it possible to pursue this method of investigation throughout the region with the hope of far reaching results.

GENERAL STRATIGRAPHICAL FEATURES.

The geological formations of the coastal area of New Jersey represent a nearly complete sequence from the Cretaceous to the Pleistocene. They form a series of thin sheets which are inclined slightly to the southeastward, so that successively later formations are encountered in passing from the northwestern portion

of the district toward the coast. Oscillation in the position of the shore line, and later denudation have occasioned, in many instances, a marked divergence from these normal conditions, so that detached areas are frequently found far removed from the body of the main outcrop.

The formations of the New Jersey coastal area and their economic equivalents are given in the following table :

Age.	Formation.	Economic Equivalent.	
Pleistocene	Columbia Formation		
Neocene	Lafayette Formation		
	Chesapeake Formation		
Eocene	Shark River Formation	Upper Marl Bed	Greensand Series.
Cretaceous	Manasquan Formation	Upper Marl Bed	Greensand Series.
	Rancocas Formation	Middle Marl Bed	Greensand Series.
	Redbank Formation	Red Sand	Greensand Series.
	Navesink Formation	Lower Marl Bed	Greensand Series.
	Matawan Formation	Clay Marls	Greensand Series.
	Raritan Formation	Plastic Clay	

The greensands characterize all the deposits from the Matawan formation to and including the Shark River formation. The glauconite appears in varying amounts and under different conditions in these several formations, so that the lithologic features are often sufficiently distinctive and persistent to be of the greatest service in the determination of the horizons. The presence of greensand has not been observed in the Raritan formation which underlies, nor in the Chesapeake formation which overlies, this series of glauconitic deposits.

DESCRIPTION OF THE FORMATIONS.

Matawan formation (Clay Marls).—On account of the extensive and typical development of the Clay Marls on the shore of the Raritan Bay in the vicinity of Matawan Creek, and along the banks of the latter stream, the name Matawan formation is proposed for the deposits of this horizon.

The greensand is a less pronounced feature than in the overlying formations. The deposits consist for the most part of dark colored clays with interbedded layers of sand, the latter becoming very pronounced in the upper portion of the formation. At some points beds of greensand appear, but they are generally

thin and of very narrow geographical extent. The deposits are largely fragmental, with here and there an admixture of carbonate of lime derived from the shells of organisms.

The most extensive section is afforded by the bluffs on the shores of the Raritan Bay, between the mouth of Cheesequake Creek and the Navesink Highlands. From this point the formation extends southwestward across the state, the best exposures being found along the stream channels entering the Delaware River from the east. Both along Crosswicks and Pensauken Creeks the strata are highly fossiliferous, at the latter locality over a hundred species having been identified. In the main the forms are the same as those in the overlying Navesink formation, although some are distinctive.

From the surface outcrops the Matawan formation has been estimated to have a thickness of 275 feet.

The most striking differences both in the character of the materials and the thickness of the beds, are shown by well borings along the line of dip. A recent boring at Asbury Park penetrated the Navesink formation (Lower Marl Bed) at 400 feet, beyond which for a distance of over 400 feet typical Clay Marls were encountered. From 750 to 780 feet glauconitic layers were found, while the deposits in general are finer and more regularly stratified than in the surface outcrops to the westward.

Navesink formation. (Lower Marl Bed).—The lower Marl Bed has an extensive development throughout the region of the Navesink Highlands, in the vicinity of the village of Navesink, and along the north bank of the Navesink River, so that the name of Navesink formation may be with propriety employed.

Greensand forms the distinguishing feature of the deposits. The lower portion is frequently quite sandy, in this respect showing the change from the sandy layers of the upper portion of the Matawan formation, upon which it lies conformably, to the typical greensands of the Navesink formation. The upper portion again shows the presence of much land derived material; it is highly argillaceous and just at the top frequently arenaceous. The greensands along the thinned out western edge of the Navesink forma-

tion have been oxidized to so great an extent that their separation from the red sands of the Redbank formation is often a difficult matter.

On account of the great economic importance of the greensand beds of the Navesink formation frequent pits have been dug into it all along its line of outcrop from the northern to the southern end of the district. As a result the strata may be studied to great advantage.

A magnificent exposure is found in the great bluffs of the Navesink Highlands facing the Raritan Bay, while excellent sections are to be found along many of the streams that cut through the formation. The beds are highly fossiliferous and the most varied fauna in the New Jersey Cretaceous is found at this horizon. Between 300 and 400 species have been described.

The Navesink formation has a pretty constant thickness of 40 feet, although locally ranging from 30 to 60 feet. The deposits have been found to be remarkably persistent in character both along the strike and dip, so far as they have been examined.

Redbank formation (Red Sand).—The bright red sands of this formation afford one of the most striking features of the country throughout the marl district. They are extensively developed in the vicinity of Redbank, and on that account the name Redbank formation is proposed for the deposits of this horizon.

The strata are glauconitic throughout, although the great preponderance of coarse arenaceous sediments has facilitated the oxidation of the greensand, changing the green color of the beds to red or brown. The lower portion of the Redbank formation is often composed of black sand or sandy clay, while at the top of the formation there is an indurated clayey layer generally of a distinctly greenish color. This hardened stratum has had an important influence in the development of the topography of the marl district, and especially in the extreme north the higher hills are largely due to its presence. The fossils are in the main the same as in the preceding formations, but on account of their poor preservation have not up to the present time been very fully studied. The indurated layers have afforded the greater number.

The formation has a rather constant thickness of 100 feet.

Rancocas formation (Middle Marl Bed).—The Middle Marl Bed is not as prominent a feature in Monmouth county where the type localities for the other formations are found as farther southward. The Rancocas Creek in Burlington county cuts through the Middle Marl Bed exposing a full sequence of the deposits of that formation, while in the neighboring area extensive exposures of the strata are found.

The formation is largely a greensand, although much more highly glauconitic in the lower than in the upper half of the formation. Although the lower half is largely a pure greensand, it becomes in some portions of the state very argillaceous toward the base, forming the so-called "chocolate marl," while toward the top it becomes crowded with shells, the upper two feet characterized by the presence of *Terebratula Harlani*, the most persistent fossiliferous zone in the state. The upper half of the formation is highly calcareous, frequently appearing as limestone ledges, known as "yellow limestone," and often containing as much as 80 per cent. of carbonate of lime. It is extremely fossiliferous, and has afforded many beautifully preserved specimens of Bryozoa, Echinodermata and Foraminifera. The fossils are, in the main, different from those in the underlying formations.

The strata reach a thickness of about 45 feet.

Manasquan formation (Lower portion of the Upper Marl Bed).—The name Manasquan Marl was in an earlier publication made to include the Yellow Sand, together with the "green sand" and "ash marl" of the Upper Marl Bed of Professor Cook. For that horizon the term Manasquan formation is retained. It is typically developed in the valley of the Manasquan River and its tributaries.

Like the preceding formation it is essentially a greensand throughout, although distinctly quartzose in the lower part, and at times argillaceous in the upper layers. The fossils so far as observed are confined exclusively to the more highly greensand member, but the number of species is not large. The high per-

centage of soluble phosphates in the Manasquan marl has long given it a high reputation as a fertilizer.

The thickness of the strata has been estimated at 65 feet.

Shark River formation (Upper portion of the Upper Marl Bed).—The term Shark River Marl was earlier employed by the writer to embrace the "blue marl" of the Upper Marl Bed, which has been generally referred in recent years to the Eocene, although the beds are conformable with the underlying strata concerning whose Cretaceous age there is apparent unanimity of opinion.

The Shark River formation is a characteristic greensand with a slight admixture of argillaceous materials, while a hardened and stony layer is found directly at the top. The fossils are numerous, but cannot be readily compared with those from the Eocene areas to the southward. The strata of the Shark River formation have not been found at any point to exceed 12 feet in thickness.

The Shark River formation closes the series of greensand deposits. It is unconformably overlain by strata of a very different character which show evidence of marked mechanical disturbances and rapid deposition.

Throughout the entire sequence of deposits just described, the presence of greensand has been the most distinguishing feature. Its origin is therefore a matter of great importance to the understanding of the several formations, and will be briefly discussed.

ORIGIN OF GREENSAND.

Greensand has been found in greater or less amounts at nearly every geological horizon, from the Cambrian down to the present time. It is not an original deposit of clastic origin, but secondary in character. An examination into the conditions of production which surround those deposits forming upon the floor of existing seas will afford an explanation of the strata of past geological time.

Great light has been thrown upon this subject as a result of he deep-sea dredgings which have been made in recent years

by the vessels sent out on scientific expeditions by the various governments of Europe and our own. The most important of these expeditions has been that of the Challenger, sent out by the British government in the years 1872–76. In the report upon the Deep Sea Deposits recently published as a result of that expedition, Professors Murray and Renard, the authors, present the latest results upon the character and distribution of greensand, and, at the same time, propose a theory to account for the chemical changes which have taken place to produce the mineral glauconite which characterizes all greensand deposits.

A typical greensand is composed of glauconite associated with greater or less amounts of land-derived material. Among the more common minerals thus found are quartz, feldspar, hornblende, magnetite, augite, zircon, epidote, tourmaline and garnet, together with fragments of the continental rocks, such as gneiss, mica-shist, granite, diabase, etc. A variable amount of calcareous matter derived from the shells of organisms is also present.

The glauconite occurs in minute grains, seldom exceeding 1 mm. in diameter, although they may become agglomerated into nodules several centimeters in diameter by means of a phosphatic cement. The grains are always more or less rounded, and at times mammillated, with irregular surface outline. They are generally black or dark green in color, but become brighter green upon being crushed. The surface of the grains is sometimes covered with fine punctures, while at other times it is smooth and shining. Some of these glauconitic grains are distinct internal casts of foraminifera, and of other calcareous shells, but more often they only reproduce indistinctly the form of the chambers, or show no definite connection with the organisms in which they originated.

It is estimated that greensand deposits cover approximately 1,000,000 square miles of the sea floor. They are found limited to those portions adjacent to the coasts, and, for the most part, along the higher parts of the continental slopes where land-derived materials are deposited in perceptible, yet small amounts. The production of glauconite seldom reaches to greater depths

than 900 fathoms, and most commonly takes place between 100 and 200 fathoms. The entrance of large rivers into the sea or the prevalence of strong currents would tend to interfere with its formation, so that the area of distribution of greensand is seldom continuous for great distances.

Although greensand is not known to be formed except in the presence of land-derived materials its production is accomplished through the intervention of foraminifera. Their connection with the formation of glauconite was first shown by Ehrenberg[1] in 1855 as the result of a study of greensand from many deposits in Europe and America. Professor Bailey[2] the succeeding year stated that the formation of greensand is likewise taking place on the floor of existing seas, and under the same conditions that existed in past geological ages.

According to Murray and Renard the chambers become filled with muddy sediment, and "if we admit that the organic matter enclosed in the shell, and in the mud itself, transforms the iron in the mud into sulphide, which may be oxidized into hydrate, sulphur being at the same time liberated, this sulphur would become oxidized into sulphuric acid, which would decompose the fine clay, setting free colloid silica, alumina being removed in solution ; thus we have colloid silica and hydrated oxide of iron in a state most suitable for their combination." The potash which is necessary to complete the composition of glauconite may be derived from the decomposition of the fragments of crystalline rocks or their common constituents, orthoclase and white mica.

Two conditions then are requisite for the production of glauconite, first the deposition of mineral particles of land-derived origin; and second, the presence of foraminifera. In the absence of either the production of greensand will not take place. It is further seen that the formation of greensand is retarded and finally ceases altogether as the amount of deposition of land-derived materials increases adjacent to the coasts. Only

[1] Abhandl. d. k. Akad. d. Wissenschaften zu Berlin, 1855, pp. 85–176.

[2] Boston Soc. Nat. Hist., Proc., Vol. 5, 1856, pp. 364–368.

then within circumscribed limits, which are constantly subject to modification, is the production of greensand possible.

GENESIS OF THE DEPOSITS.

The opening of the Cretaceous period along the Atlantic border witnessed the deposition of large amounts of irregularly stratified sands and clays together with beds of gravel in the vicinity of the coasts. It was a period of great mechanical disturbance over the area of deposition, and both the physical and faunal characters of the strata point to the close proximity of land, while enclosed basins doubtless existed for a portion of the time.

With the opening of the epoch of greensand deposition, as represented in the Matawan formation, much the same conditions at first prevailed. Alternating beds of sand and clay were laid down, but gradually the coarser elements disappeared, deposition became less rapid and greensand was locally developed. The conditions for greensand production were not widely extended nor long existent, for successive periods of rapid and slow accumulation of materials continued to the close of Matawan deposition.

With the advent of the Navesink epoch land-derived materials became greatly reduced in volume and shortly ceased almost altogether, so that throughout the area of deposition there was formed at this horizon some forty feet of highly glauconitic greensand. Toward the close of this period terrigenous deposits became more pronounced, but the production of glauconite did not altogether cease.

With the opening of the next epoch, represented by the Redbank formation, dark sands in which the proportion of glauconite was very small were at first deposited. Throughout the whole series of beds glauconite is found distributed in greater or less amounts, but at no time did its production reach the prominence that it had during the previous epoch. The marked admixture of coarse elements throughout most of the deposits rendered them later subject to the ready percolation of water by which

the complete oxidation of the glauconite was accomplished. Toward the close of the Redbank epoch finer sediments prevailed, and there is every evidence that land-derived materials found ingress to the area of deposition in gradually lessening amounts.

The succeeding Rancocas epoch was a time of slow accumulation of continental materials so that the production of glauconite went on unhindered. During the latter portion of the epoch, however, there must have been a great profusion of animal life, for the deposits show a marked admixture of carbonate of lime, while in many instances the shells are still in an excellent state of preservation. The formation of glauconite was not interrupted, although its relative proportion is at times much diminished by the great amount of carbonate of lime which may in some instances reach eighty per cent. of the whole.

The Manasquan epoch was characterized throughout by the constant formation of greensand beds, although land-derived materials in considerable amounts reached the area of deposition during the early portion of the period.

No very marked changes apparently affected the region toward or at the close of the Cretaceous, but the same conditions persisted on into the Eocene, as shown in the Shark River formation, during which period similar deposits with very different types of animal remains were accumulated. At the close of the Shark River epoch the conditions favorable for the formation of greensand ceased, not to be again revived during the period of formation of the coastal deposits in New Jersey.

The succeeding epochs gave proof of much shallower waters, while the ancient Cretaceous-Eocene sea floor frequently stood above sea level and along its landward portions constantly lost as the result of erosion. As the land rose higher and higher in late geological history further inroads were made until the deeper portions of the ancient sea bottom were exposed by the forces of denudation.

SOURCE OF THE MATERIALS.

The source of the materials which constitute the several formations of the coastal region of New Jersey has not been

altogether satisfactorily explained, although the deposits indicate that they were largely derived from crystalline rocks.

That the red sandstones and shales of the Jura-Trias (Newark Formation) which adjoin the coastal series upon the landward side have not been the source of the materials is a striking fact, and one which has been largely commented on in the past. By some it has been supposed that an area of crystallines must have existed to the eastward to afford the materials for the deposits under consideration. A study of the drainage of the Jura-Trias belt which separates the coastal formations from the area of crystalline rocks beyond, is of interest, however, in showing the probable extension of the coastal deposits quite over the red sandstones and shales of the Jura-Trias to the border of the crystalline region and at the same time affords a sufficient explanation for the absence of sediments derived from the Jura-Trias itself. The evidence for this has been recently presented by Davis[1] in the National Geological Magazine, and the reader is referred to the article for a fuller explanation of the subject.

Accepting the explanation of Davis as highly probable we may look for the source of the land-derived materials out of which the greensand deposits are formed, in northwestern New Jersey, eastern Pennsylvania and southeastern New York, in a portion of that tract of crystalline rocks which stretches along the eastern side of the continent. A separation of the mineral constituents of the greensand deposits shows a preponderance of both the constituent and accessory minerals which characterize those rocks. It seems conclusive, therefore, that the area mentioned was the source of the materials for the greensand deposits of eastern New Jersey.

TAXONOMY.

The geological formations of New Jersey early attracted the attention of geologists, and Professor Peter Kalm[2] of Sweden,

[1] Nat. Geog. Mag., Vol. II., No. 2, pp. 1-30, 1890.

[2] En Resa til Norra America 8vo. 3 vols. 1753-61, Stockholm. Translations in English by J. R. Forster 1st. Ed. 1770-71, 2nd. Ed. 1772, another Ed. in J. Pinkerton's Voyages, Vol. 13, 1812; in German by J. H. Murray, 1754-64; in French by L. W. Marchand, 1859.

who was sent out in 1749 under the auspices of the Royal Academy of Sciences to make a study of the various branches of natural history in America, presents many interesting observations concerning the deposits under consideration. He spent much of his time in New Jersey.

In 1777, Dr. Johann David Schoepf[1] of Germany, visited America in order to study the geological features of the eastern portion of the continent. His observations and comparisons of the coastal plain formations, especially of New Jersey, mark considerable advance over those of Kalm. The importance of his investigations have not been very generally recognized by later writers, but he showed a remarkably keen insight into the geology of eastern America which was lacking on the part of some of his successors.

The first attempt at a correlation of the deposits of New Jersey with the geological column then established in Europe was made by William Maclure[2] in 1809, in his "Observations upon the Geology of the United States." In this publication the coastal deposits of New Jersey are collectively referred to the "Alluvial formation," the fourth of the main divisions of geological strata proposed by Werner. The work was subsequently revised and enlarged, appearing in book form in 1817.[3]

Professor John Finch was the first to propose a division in the coastal plain deposits of New Jersey. In his "Geological Essay on the Tertiary Formations in America" he states that what has been called the "Alluvial formation" by earlier writers "is identical and contemporaneous with the newer Secondary and Tertiary formations" of other portions of the globe.

A few years subsequent to this, Professor Lardner Vanuxem[4] through his friend Dr. S. G. Morton, presented the criteria for a

[1] Beiträge zur mineralogischen Kenntniss des östlichen Theils von Nord Amerika und seiner Gebürge. 8vo, 1787, 194 pp. Erlangen.

[2] Amer. Phil. Soc. Trans. Vol. 6, 1809, pp. 411–428. Translation in Journal de Physique, Vol. 69, 1809, pp. 204–213 and Vol. 72, 1811, pp. 137–165.

[3] Philadelphia, 8vo, 130 pp. Also in Amer. Phil. Soc. Trans. new series, Vol. 1, 1817 pp. 1–92; and Leonard's Zeitschrift, Band 1, 1826, pp. 124–138.

[4] Amer. Jour. Sci. Vol. 7, 1824, pp. 31–43.

more complete and definite recognition of the several members of the coastal series in which both the Cretaceous and Tertiary formations were described in some detail.

With the establishment of the official geological survey of New Jersey under the direction of Professor H. D. Rogers[1] the first attempt was made at a detailed differentiation of the local deposits. The formations, beginning at the bottom, were designated as follows: *Clays and Sands, Greensand, Limestone, Ferruginous Sand,* and *Brown Sandstone.* Although the various members were not clearly defined and widely different materials were included under the same division, yet the easterly dip of the strata was observed and the broader distinctions in the stratigraphy of the area were recognized.

Dr. T. A. Conrad,[2] in 1848, first suggested that the upper portion of the greensand series was of later age than the Cretaceous, a conclusion which he more fully elaborated at a later date.

The second geological survey of New Jersey, organized in 1854, under the direction of Wm. Kitchell, had as assistant geologist, George H. Cook, who a few years later became himself State Geologist, a position he held for over twenty-five years, until his death in 1889. He devoted from the first much attention to the greensands, and his classification of the strata has met with wide acceptance. It is elaborated in much detail in the Geology of New Jersey, published in 1868. The series of formations as recognized by Professor Cook is as follows, beginning with the oldest: *Plastic Clay, Clay Marls, Lower Marl Bed, Red Sand, Middle Marl Bed, Yellow Sand,* and *Upper Marl Bed.* Subsequently, Professor Cook[3] considered that an unconformity existed between the Eocene and Cretaceous members of the Upper Marl Bed.

There is no area in this country where the several formations have been studied more with reference to their own characteristics

[1] Philadelphia Acad. Nat. Sci. Jour. Vol. 6, 1828, pp. 59–71.

[2] Philadelphia Acad. Nat. Sci. Jour. new ser. Vol. 1, 1848, p. 129. Philadelphia Acad. Nat. Sci. Proc. Vol. 17, 1865, pp. 71, 72.

[3] Report of the State Geologist for 1883, pp. 13–19.

and less with reference to the supposed similarity of faunas and deposits with other and particularly European horizons.

The difficulties in the way of extended correlation are so great that for purposes of study it is often necessary to apply local names to the several formations of a particular district. There are, beyond a doubt, objections to the multiplication of names of geological horizons and already accepted terms should be employed as far as possible, but very frequently they prove to be inadequate for stratigraphical requirements. Such is the case in the New Jersey area.

Outside of the major divisions of the geological column it is impossible to employ the terms of European authors. All such attempts have, upon critical examination, failed to stand the test. The lithological and faunal characteristics show such wide variations that definite correlations of minor horizons are impossible. The geological formations of America must be studied first upon their own merits and only after a complete understanding of them has been gained can satisfactory comparisons be made with foreign areas. A detailed correlation of the New Jersey formations with European will therefore not be attempted.

Again the conditions under which the strata of the different portions of this country were deposited, are so varied that the same terms are not applicable over wide areas. The formations of the Interior are in a marked degree dissimilar from those of the Atlantic border, and even throughout the coastal plain very considerable differences are found in its various portions. Correlations of more satisfactory character can be made here than with foreign areas, but many obstacles debar the geologist from the full consummation of his task. It is possible to show in a general way the equivalency of the deposits upon the Atlantic border with those in the Gulf, the Interior, or on the Pacific coast, although in the case of individual formations such comparisons are of doubtful character.

Dr. White[1] in his admirable essay upon the Cretaceous of North America, discusses very critically the evidence for the

[1] Bull. U. S. Geol. Survey, 82, 1891, 273 pp.

correlation of the New Jersey greensands, but does not attempt to separate the individual members of the series beyond the reference of the upper member to the Eocene, as was also done by the writer[1] in his report upon the Eocene. It is impossible however, to satisfactorily correlate this upper member of the greensand series with the Eocene elsewhere, and it is not known how much of that horizon is included in it. It has been generally thought to represent the Lower Eocene of other regions. Concerning the other formations of the greensand series there seems to be little doubt of their reference to the Upper Cretaceous, although they probably do not include its earlier portions. Many of the same species have been found in the Cretaceous areas of the South Atlantic and Gulf States. Stanton[2] has recognized thirty-five species as identical in Alabama, eighty-six in Mississippi, and fifty-four in Texas. Some of the species which are very much restricted in the New Jersey area, appear to have a greater vertical range in the Gulf region. It is therefore very difficult to delimit equivalent horizons. It is not unlikely that a fuller knowledge of the formations may render it possible to make more detailed correlations, but at present it is impossible.

On these grounds, therefore, an independent classification of the New Jersey deposits is demanded. The objections to the use of lithologic terms have been already cited, as well as the grounds for employing the place names adopted.

GENERAL CONCLUSIONS.

The greensand strata of New Jersey constitute a conformable series of beds aggregating nearly 550 feet in thickness. During the Matawan epoch, when fully one-half of these deposits were being laid down, land-derived materials reached the sea in large amounts, frequently interfering with the formation of glauconite, which is much less prominent at this horizon than later. During the succeeding epochs the production of greensand was much

[1] Bull. U. S. Geol. Survey, 83, 1891, 173 pp.

[2] Bull. U. S. Geol. Survey, 82, 1891, p. 84.

more constant, although there were times when it became greatly reduced in amount on account of the advent of large amounts of sand and mud from the adjacent coasts.

From the known conditions requisite for the production of glauconite upon the bed of existing seas, and the possible position of the coast line in Cretaceous time, it seems likely that the greensands now outcropping at the surface were laid down from fifteen to thirty miles off the coast. Frequent changes of level no doubt took place, but the variations in the character of the deposits were probably quite as much due to fluctuations in the currents as to pronounced changes in the position of the coast line.

The marked thickening of the Matawan formation seaward, as shown by the well-boring at Asbury Park, is of interest as indicating the more permanent character of the deposition outside the area of mechanical disturbance such as characterized the shallower portions of the Matawan sea floor.

The alterations which have taken place in the exposed portions of the deposits are oftentimes widespread, and in the case of the indurated layers at the top of the Redbank formation have determined to a large extent the topography of the greensand district.

Many interesting problems are presented for further study, but it is hoped that this paper may contribute somewhat to a clearer understanding of greensand deposits in general, and those of the New Jersey area in particular.

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THE NATURE OF COAL HORIZONS.

THE Coal Measures of the Mississippi valley occupy an area of more than 120,000 square miles. They extend in an almost unbroken field from the western flank of the Appalachians on the east to beyond the Missouri river on the west. Separating the area into two somewhat unequal parts is the Mississippi river along the course of which are exposed older rocks. The Coal Measures may have been at one time continuous over the central portion, but the outcrops of the more ancient rocks along the borders of the Mississippi is probably not due entirely to unaided erosion but in part to slight folding, an anticlinal axis coinciding approximately with the line of the great river.

The geological history of the eastern and western areas, which are sometimes called respectively the Central and the Western Interior coal fields, is probably similar, though in some particular phases there is a divergence which dates back prior to the close of the Lower Carboniferous. The northern portion of the Coal Measures west of the Mississippi forms a broad bay-like expansion opening to the westward. Beyond the Missouri river the strata are hidden from view by newer sediments. The most productive portion of the Western Interior coal field is a marginal zone extending from northcentral Iowa southeastward to northeastern Missouri, thence sweeping to the westward around the Ozark uplift into Indian Territory and continuing on into central Texas. The interior portion of the bay-like expansion of Coal Measures is as a general thing unproductive, though a few thin seams of coal do occur.

Everywhere throughout the region the stratigraphical details present great simplicity, being almost free from the effects of orographic movements. The lithological characters of any one locality are repeated again and again in the same monotonous

succession. The faunal and floral features are practically identical from one end of the great coal basin to the other.

The greatest interest, economically and geologically, in the Carboniferous basin centers around the coal deposits. Their disposition perhaps comes first in importance, both from the standpoint of the operator and of the geologist. The subject is certainly one of wide-reaching import.

There is now abundant evidence to show that the Western Interior coal field at the time of deposition was for the most part a broad, shallow basin opening to the westward into the great continental sea which then occupied most of what is now known as western North America. That the Coal Measures of the region were laid down during a period of gradual, prolonged, though often checked, subsidence is evidenced by all stratigraphical and lithological details, as well as by the characteristic faunal peculiarities. That the coal beds originated largely in coastal swamps of limited breadth but, with some interruptions, of very considerable length, stretching out near sea level for long distances and sending out minor extensions into the old rivers and estuaries is fully warranted by the facts disclosed everywhere. On the low, slowly sinking shores there prevailed at certain times a similarity of physical conditions especially favorable to coal formation. During these intervals unusual amounts of coaly material were allowed to accumulate and to be preserved in places, the period being preëminently one of coal growth, at least for a given province. The great stratigraphic plane marking each record may be appropriately termed a "Coal Horizon."

In stratigraphy, a geological horizon is a level recognizable over a considerable geographical extent, having a more or less well defined stratigraphical position, distinctive as to lithological features and characterized by a particular set of fossils. The term in a broad sense is almost equivalent to formation, and has been used as indefinitely. In its more limited meaning it is applied properly to a minor part or zone of the smallest stratigraphical unit having a commonly accepted specific name. Un-

derstood in the same way, a "Coal Horizon" represents an even more limited expansion, where coal forming materials have accumulated. Practically it is one of the greater planes of sedimentation, marking a distinct episode in the deposition of a series of strata. Theoretically it represents not a phenomenon, but rather a set of conditions, a period during which the physical circumstances were similar over a considerable marginal portion of a geological province. From an economic standpoint it stands not for a continuous bed of mineral fuel, but a stratigraphical level where workable beds are more likely to occur than elsewhere, and where the coal is to be especially sought for in a wide belt fringing a great coal basin. It is not to be inferred, then, that the mineral is equally developed on a given

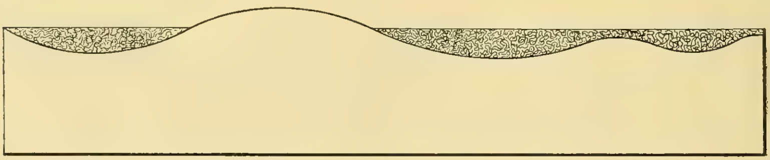

FIG. 1. Coal Horizon at time of formation; parallel to shore line.

horizon in all portions of this marginal border. In some places the accumulations of plant remains are much greater than in others; limited basins and troughs of unusual thicknesses are there found. Elsewhere the old vegetable materials are meagerly represented; only thin seams of coaly matter are there preserved. Wide intervals of sandstone and shale often separate adjoining basins, or ancient land elevations may cut off one area from another. (Figure 1). Yet, through all of the many irregularities of deposition and subsequent deformation there are nevertheless discernible, certain levels quite well defined at which coal beds are very much better developed than at others; clearly marked coal horizons they are, broad in extent and capable, in the case of the greater ones under favorable circumstances, of being traced over a large part of a given Coal Measure province. The coal may not be present in a continuous seam over the whole border district and probably never is; but along much of the

margin of the coal horizon, which at one time must have stood near the sea level for a considerable period, are innumerable basins separated from one another perhaps, yet to all appearances formed contemporaneously. Now they may thicken into sharply defined lenticular beds; now thin out to mere films, or disappear altogether; and again further on they assume the form of extensive lens-shaped sheets. During deposition, as subsidence became too rapid or the sea too deep for the proper accumulations of vegetable material, sediments were carried in covering the plant beds. Or, if elevation took place the old swamps, already shut off from free access to the sea, were subject to the agencies of denudation and were partially or entirely removed. As favorable physical conditions again set in the same course of events might be repeated.

In considering the relations of the different coal horizons to one another an approximate parallelism may be made out. Not a strict parallelism of the nature which Andrews[1] claimed to be true in Ohio, and which Newberry[2] subsequently stated to be entirely unsubstantiated by facts, but an approximate parallelism in a broad way.

There was apparently a germ of truth in the idea of the first named author, though he was probably unfortunate in the choice of a name for his theory. Moreover, none of his writings indicate that he understood the problem in the way that recent investigations reveal it. His statements all seem to show that, while he was manifestly on the right path, only one side of the subject had been presented to him, just as, quite recently, the question has been discussed from the opposite extreme. Andrews' views are perhaps best expressed in the following paragraph taken from his paper[3] on the subject:

"I have never found the slightest proof of the formation of a seam of coal over hills or high grounds. The parallelism of the seams, of which further mention will be made, forbids it.

[1] Geol. Sur. Ohio, Vol. I, p. 348. Columbus, 1873.

[2] Geol. Sur. Ohio, Vol. I, p. 169. Columbus, 1874.

[3] Geol. Sur. Ohio, Vol. I, pp. 348–350. Columbus, 1873.

. . . . So far as my observations go, I have never found an instance where two distinct seams of coal came together or, conversely, where a seam became divided and its parts continued to diverge for a long or indefinite distance. It is not uncommon to find, in a seam of coal, the proof that the coal marsh had in it local depressions, which were filled with sediments, making a soil on which new vegetation grew, and thus the seam shows two parts, separated by fire clay sometimes several feet thick; but in every instance when traced I have found the parts to reunite. The two parts never diverge indefinitely. From these

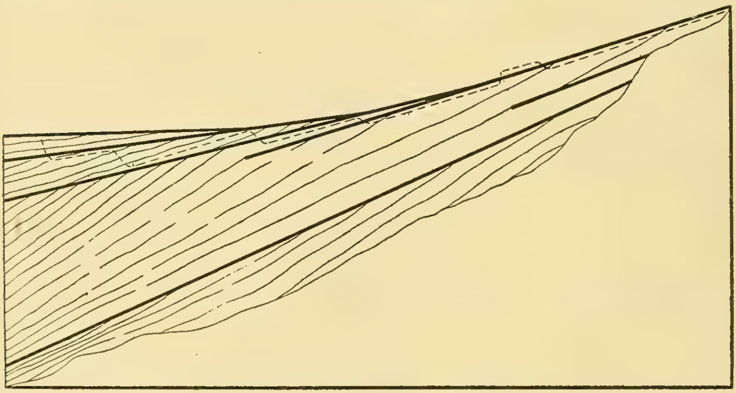

Fig. 2. Stratigraphy of Coal Beds.

statements we may infer a general law of parallelism. Such law is in harmony with the belief of the most careful observers, that our productive Coal Period was characterized by great quietness and freedom from violent local disturbances."

This describes the apparent condition of things in Ohio. The same with minor modifications and explanations may be regarded as according fairly well with the facts observed in the Iowa-Missouri coal field.

On the other hand there are many who, with Newberry, have directly opposed any approach to the recognition of the parallelism of coal veins. Among the latest opinions on this side of the discussion is one expressed by Winslow,[1] who in considering

[1] Geol. Sur. Missouri, Rep. Coal, pp. 28–30. Jefferson City, 1891.

the stratigraphy of Missouri coal seams is led to believe that the different veins diverge from one another in a manner best explained by the preceding diagram, the dotted line representing post-Carboniferous erosion. (Figure 2).

These conditions also accord in the main with the facts observed in all the Western coal fields.

An attempt to harmonize the two seemingly very divergent and even contradictory theories is apparently fruitless. But a more careful examination of the subject shows that the two theories are manifestly not based on facts taken from the same point of view, but from quite different positions. Andrews' idea may be taken as representing a cross section of the coal bearing strata taken parallel to the general course of the shore ; Winslow's a section at right angles.

In districts where mountains are being elevated, orographic movements in the earth's crust continue to be felt for long distances from the line of maximum disturbances. If a great sea or an ocean occupies a region affected to a moderate extent by the oscillations, an extended shore line trends approximately with the axis of the mountain system, for the more important minor corrugations commonly run in similar parallel lines. The direction of maximum change in the inclination of strata is therefore at right angles to the axes of the folds, and hence in a broad way perpendicular to the shore line. The direction of minimum change in tilting is, under ordinary conditions, the same as the axes, or parallel to the shore. Bearing these suggestions in mind geological cross sections, under favorable circumstances of examination, would show a general parallelism of coal beds when made in one way ; a decided tendency to non-parallelism when constructed in the other.

Granting, then, an old, uneven land surface, such as is known to have existed in Carboniferous times in the upper Mississippi basin, with the waters of the sea and the marginal maritime flats gradually creeping inland, it would naturally be expected that in the case of any one of the marshy plains skirting the shores for any great distance there would be a very tortuous boundary on

the land side and a somewhat less sinuous line on the seaward side ; on the one hand were probably low hills and uplands sending out spurs here and there which cut off one marsh from another and often allowing long open stretches of low upland to reach out even to the waters of the sea itself; on the other hand were often narrow coastal plains rising scarcely above sea level, but, to a great extent, shutting off very effectually the saline waters from the swamps. Viewed areally, the productive portion of one of the great coal horizons is a wide irregular zone running in a tortuous course around a more or less extensive portion of the margin of a coal bearing basin included within the limits of a geological province. Examined at the present time coal horizons present, with all the irregularities of original deposition, subsequent change and deformation, a quite different aspect from the ideally perfect level of the ancient surface or zone which existed during the period of formation. In one direction, parallel to the shore, there is a series of minor saucer-shaped basins strung along on about the same great stratigraphical plane. They may rise or fall as the other strata change in inclination. They may be separated by wide stretches of sandstone or shale, or may come together in places. In the different basins the original vegetable materials in becoming compact shrink most in bulk in the middle, thus allowing the margins to remain considerably higher than the center. This is more noticeable in small basins than in large ones. Then, too, the fact that the direction of minimum movement in the changes of level was, as has been shown, parallel to the prevailing trend of the shore does not preclude even in this direction a certain amount of tilting of the strata either by the rising or the sinking of one portion of the shore more rapidly than another; or by the passage of some of the minor folds in directions not strictly harmonious with the general movement.

When a new cycle of vegetable accumulation took place the coastal swamps would again spread out at sea level, but not necessarily on planes exactly parallel to the horizon previously formed. Horizons which were separated to very considerable distances by

shales or other strata, probably are rarely exactly parallel to one another, or if so, the parallelism is purely coincidental. There are many causes which in places lead to the non-parallelism of the coal horizons. The original bottom of the sea may have been very uneven, as is well shown in the very irregular surface of the Saint Louis limestone on which the Coal Measures were laid down. Or, in two different seams the inequalities may be great, the extremes often occurring in the same locality, and thus presenting a much greater apparent unevenness than really exists. Erosion or currents may have altered the position of the seams or parts of them. The top of the seams which were originally level became subsequently depressed in the center more than at the margins. There are also other causes tending to widen the seeming discrepancies. (Figure 3).

FIG. 3. Coal Horizon as it now exists; parallel to shore line.

In another direction, at right angles to the old shore, the minor basins along the different horizons may appear to show no tendency to parallelism at all. The approach to the parallel condition is inversely proportional to the amount of deformation occurring in the region at the time of the formation of the coal beds. Instead also of the seam being continuous for a considerable distance across the coal basins, as may be inferred from Winslow's graphic representation, the productive coal strata should be confined to a limited marginal area and the coal horizon would only extend into the interior as a great stratigraphical plane, not easily recognizable perhaps, nor with any of the mineral itself to mark it. (Figure 4).

The conditions described apply particularly to the coal fields of Iowa and Missouri, where comparatively few disturbances of the strata have taken place. The relations are relatively simple. But

in Ohio and Pennsylvania, as the mountains are approached, the structure increases rapidly in complexity, until in the highly folded and faulted districts attempts to follow out the original state of things may become utterly hopeless.

The majority of the larger coal deposits of the Western Interior field may be considered then as having been formed in swamps skirting a great shallow gulf, the extent of the produc-

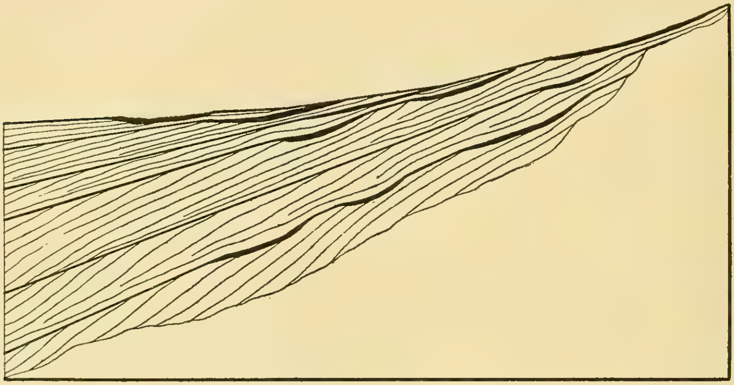

FIG. 4. Coal Horizon viewed at right angles to shore line.

tive portions of the different horizons being in a measure dependent upon the length of time the physical conditions were favorable to coal formation. Many short minor episodes doubtless existed between the larger ones, during which comparatively small accumulations of vegetable material took place.

Another fact to be taken into consideration is that all the coal of the region was not formed in marine swamps, but that some of the minor basins were doubtless originally a very considerable distance from the sea, while certain others were formed where open sea conditions prevailed largely. A few seams also appear to have been formed as drift materials in estuaries at the mouths of streams.

CHARLES ROLLIN KEYES.

THE ARKANSAS COAL MEASURES IN THEIR RELATION TO THE PACIFIC CARBONIFEROUS PROVINCE.[1]

CONTENTS.

INTRODUCTION.

Marine fossils of Coal Measure age were found by the Geological Survey of Arkansas in eighteen places, fourteen in the lower division and four in the upper. These localities extend from Independence county westward to Indian Territory, and

[1] From an unpublished report of the Geological Survey of Arkansas, by permission of the Director, John C. Branner.

give a total of 48 genera and 78 species, 31 species in the Lower Coal Measures, and 51 in the Upper, with 4 species common to both.

It is not thought that this small number of species represents the entire fauna, or that only four species are common to the two divisions, for the collections were much too scattered and too meager to exhaust the possibilities.

But the fauna is a poor one, such as one would expect to wander in from deeper waters, whenever a slight subsidence had made the shallow water a little more habitable. The fauna could not become well established, because the conditions soon reverted to their old state, and the inhabitants of the seas were forced to migrate or were exterminated.

There is, therefore, no gradual transition here from the fauna of the Lower Carboniferous limestone, since the presence of these fossils depends on the transgression of the sea on land areas, and the fossils of the Lower Coal Measures are just as different from those of the Lower Carboniferous as are those of the Upper Coal Measures.

No successful division of the Coal Measures into zones has ever been carried out, and in the present state of our knowledge it cannot be done. This makes the correlation of distant localities difficult, since the vertical range of species in the Coal Measures is very little known. Therefore, the range of the species in Arkansas cannot be given any closer than the two great divisions of the Coal Measures.

COMPARISON WITH THE PERMO-CARBONIFEROUS OF KANSAS AND NEBRASKA.

The fauna of the Upper Coal Measures of Arkansas has a strong resemblance to that of youngest Paleozoic beds of Kansas and Nebraska, described as Permian by Professor Geinitz.[1]

F. B. Meek redescribes this fauna,[2] and comes to the conclusion that the rocks in question are not to be referred to the Per-

[1] "Carbonformation und Dyas in Nebraska."

[2] Final report U. S. Geol. Survey of Nebraska, etc., pp. 128 *et seq.*

mian, because he can find no paleontologic or stratigraphic break to separate them from the Carboniferous. He finds 16 genera characteristic of the Carboniferous, and 7 genera not thought to antedate the Permian in Europe, but associated with genera not thought to occur later than the Carboniferous. Meek[1] says that *Fusulina*, which occurs in great numbers in the uppermost Carboniferous beds of Nebraska, is considered in Europe to be mainly if not exclusively a Lower Carboniferous genus. In this, however, he was mistaken; his opinion dates from a time when most geologists were inclined to place all Carboniferous limestone in the Lower Carboniferous. But it is now known that the Carboniferous limestone occurs in the Upper Carboniferous about as often as in the Lower, and the *Fusulina* limestones of Sicily and Russia grade over into beds of undoubted Permian age. This is also true of corresponding beds in the upper part of the Carboniferous of Texas. In fact the *Fusulina* beds are always either Upper Carboniferous or Permian, in eastern Europe and Asia, and nearly always in America.

Although undoubtedly believing in continuity of life and formations, Meek seems to have based his reasoning on the old idea of catastrophies, since he thought that the absence of a paleontologic or stratigraphic break was a sufficient reason for calling the beds in question Upper Coal Measures rather than Permian. A large majority of the genera and species are characteristic of the Carboniferous, and this Meek thinks sufficient to offset the fact that several genera previously considered typical of Permian[2] are present.

In the Upper Coal Measures of Arkansas out of 51 species, there are 25 in common with the doubtful strata of Nebraska, and 6 other species are common to the Nebraskan Permo-Carboniferous and the Lower Coal Measures of Arkansas, but have not yet been found in the Upper Coal Measures of the latter

[1] Page 33, op. cit.

[2] In the transactions of the Kansas Academy of Science, Vol. XIII., p. 38, Robert Hay announced that Professor H. S. Williams and Professor Tschernyschew had visited the Fort Riley section, and agree that it was undoubtedly Permian.

state. But of the genera mentioned by Meek as being considered not to antedate the Permian of Europe only two are found in the Arkansas strata, namely, *Synocladia*,[1] and *Lima*.

There is therefore not sufficient reason for classing the Poteau mountain beds with the Permian, but their fauna, as well as stratigraphic position place them very high in the Coal Measures, since they agree in fauna and position with the Mississippi valley Upper Coal Measures. These beds derive an additional interest from the fact that on Poteau mountain about one thousand feet of shales, in which no fossils were sought for, lie above the thin layer from which the entire collection was taken; thus the chances of finding true Permian beds in that region are very good.

RELATIONS TO THE TEXAS UPPER CARBONIFEROUS.

The only undoubted marine Permian in America has been described by Dr. C. A. White.[2] He finds the fauna of the upper Paleozoic beds of northern Texas, discovered by Professor W. F. Cummins, to be analogous to that of the *Fusulina* limestone of Sicily, the Artinsk stage of the Ural mountains, and the upper part of the *Productus* limestone of the Salt Range, India. These strata all show that peculiar commingling of ordinary Coal Measure fossils with ammonite genera, such as *Popanoceras*, *Medlicottia*, and *Waagenoceras*, which seems to be characteristic of open sea facies of the Permian.

None of the characteristic ammonite genera were found in the Arkansas region, but nearly all the fossils found in the Arkansas Coal Measures are also found in Texas. And in the Texas region nearly all the Permian species excepting the *Ammonites* were also found in the underlying Cisco division, which faunally and stratigraphically is the equivalent of the Upper Coal Measures of Arkansas.

Goniatites (*Gastrioceras*) *baylorensis* White is represented in

[1] WAAGEN has shown, in Pal. Indica, Salt Range Fossils, I. Productus Limestone Fossils, p. 802, that *Synocladia* is not found in America, the species described by Swallow as *Synocladia biserialis* being a *Septopora*.

[2] Bulletin 77, U. S. Geological Survey.

Arkansas by the closely related species *Goniatites globulosus* Meek and Worthen.

Orthoceras rushense McChesney, is found in both areas; the *Endolobus* is possibly the same in both, or closely related; *Euomphalus subquadratus* Meek and Worthen, is common to both; *Bellerophon crassus* Meek and Worthen, is found in both areas; *Pleurophorus* sp. is probably the same in both regions.

Nearly all the Upper Carboniferous species of Texas and Arkansas are also found in Illinois, Iowa, etc., in beds that have never been thought to be other than Coal Measures. We are therefore safe in concluding, that while some of the beds in western Arkansas are very high up in the Coal Measures, none that belong above them are as yet certainly known, and the Poteau mountain syncline, across the line in Indian Territory, is the only place where there is any likelihood of finding Permian deposits.

COMPARISON WITH FOREIGN UPPER CARBONIFEROUS.

The Lo-ping fauna.—The descriptions of the fossils of the Lo-ping district of China, by Professor E. Kayser,[1] throw great light on the relations of the American Carboniferous faunas to those of Asia. Near Lo-ping, in eastern China, are found in strata overlying the coal-beds, numerous marine fossils of Upper Coal Measure age. Kayser has described 55 species, 10 not specifically identified, 15 cosmopolitan species, and 11 forms that are typically American, and belong chiefly to the Upper Coal Measures.

The 15 cosmopolitan species are also nearly all found in the American Upper Coal Measures, so that of the entire Lo-ping fauna nearly all the species are either found in America, or they have their nearest relatives there. The two regions belong to the same zoölogical province, the Pacific Carboniferous sea.

Many of these species that are very common in America and Asia are unknown or rare in Europe, which fact would tend to prove a connection with Asia by water, and the separation of the European and the American Upper Coal Measure deposits by a land barrier.

[1] RICHTHOFEN: "China," Vol. IV.

The Carboniferous plants collected by Baron von Richthofen[1] numbered about 40 species and were nearly all identical with European Carboniferous plants. The natural inference is that in those times Asia was connected with Europe by land, and that the sea opened out to the east.

Professor J. S. Newberry[2] described a small collection of Carboniferous plants from China, and found nearly all of them to belong to well-known European species. This is in perfect agreement with the conclusions drawn above.

The Salt Range beds.—In the Salt Range, in northwest India, are found Upper Carboniferous deposits, some of which resemble those of Lo-ping, China; and the *Lower Productus* limestone of India is probably of about the same age as the beds of Lo-ping, and the western American Upper Coal Measures. These deposits and their fauna are described by Professor W. Waagen,[3] and in the volume on "Geological Results" he draws parallels between the faunas of the upper Paleozoic in different countries. Many of the American species that are found at Lo-ping are also found in the Salt Range *Lower Productus* limestone. This same type of Carboniferous is found in Sumatra, where it has been described by Ferd. Roemer,[4] and on Timor, where it was described by E. Beyrich.[5] This is the furthest southward that the Indian or northern type of Upper Carboniferous is known, and indeed the deposits of Sumatra and Timor begin to show already a greater affinity for the Australian or southern type of Carboniferous.

Waagen[6] divides the Carboniferous into two types, the northern or Asiatic, and the southern or Australo-African. The northern type is found in western Europe, Russia, the Himalayas, China, the Arctic regions and North America. The southern type is developed in South Africa and Australia, and extends into Penin-

[1] RICHTHOFEN: China, Vol. IV., Abhandlung 9, Dr. A. Schenk.

[2] American Journal of Science, Vol. 126, 1883, pp. 123 *et seq.*

[3] Paleontologia Indica. Salt Range Fossils.

[4] Paleontographica, Vol. 27, 1880.

[5] Abhandlungen der Berliner Akademie der Wissenschaften, 1864.

[6] Salt Range Fossils, Geological Results, p. 239.

sular India and Afghanistan. Brazil probably belongs to this type, but is to a certain extent transitional.

The Itaitúba fauna.—A comparison of the Upper Carboniferous fauna of Itaitúba, Brazil, as described in part by Professor O. A. Derby,[1] shows that of 27 species of *Brachiopoda*, 12 are identical with American forms, although most of these are cosmopolitan. The genus *Strophalosia* is common in these beds, and as Professor Derby[2] says, the species shows affinity with the Permian. Many of the new species described by Professor Derby are closely related to the European forms. Waagen[3] says that the beds of Itaitúba are of the same age as the *Middle Productus* limestone of India, that is of the Permo-Carboniferous transition beds. The Brazilian *Strophalosia* is closely related to Australian species, indicating a closer connection with the Australian or southern Carboniferous region than with the Pacific province. Hence we infer that the Brazilian deposits may after all belong to the Upper Coal Measures, and that the difference between them and the northern Upper Coal Measures may be geographic instead of geologic.

CLASSIFICATION AND AGE OF THE ARKANSAS COAL MEASURES.

Provisional classification.—For the sake of convenience, the Coal Measures of Arkansas have been provisionally classified by the Survey as Upper or Productive, and Lower or Barren Coal Measures. This division is not based on any paleontologic or stratigraphic break, but merely on the occurrence or non-occurrence of coal.

The divisions that are recognized in Pennsylvania could not be recognized in Arkansas, but the strata of the two regions are correlated as far as possible with the scanty data now at hand.

The Lower Coal Measures.—Of the age of the Lower Coal Measures we have only stratigraphic evidence, their position above the limestone of the Lower Carboniferous, and below the coal-bearing beds of the Lower Coal Measures being unmistakable.

[1] Bulletin Cornell University, Vol. I., No. 2.

[2] Op. cit., p. 60.

[3] Salt Range Fossils, "Geological Results," p. 207.

But their known fauna and flora have been too limited and too indecisive to enable us to correlate subdivisions with those of other Carboniferous areas, since collections have been made in but few places, and these chiefly in sandstones, where the preservation of fossils is usually unsatisfactory, and their determination uncertain.

But the Lower Coal Measures correspond in a general way to the Strawn and the Canyon divisions of Texas, the Pottsville conglomerate series, the Lower Productive Coal Measures, and part of the Lower Barren Coal Measures of Pennsylvania.

The Upper Coal Measures.—The Arkansas Upper Coal Measures correspond to the lower part of the Cisco of Texas, and belong just at the top of the true Carboniferous, and below the transitional Permo-Carboniferous or Artinsk stage, to which latter age the uppermost Cisco beds of Texas, with *Ammonites* (*Popanoceras*) *parkeri*[1] Heilprin belong. These may be the equivalents of the Poteau mountain marine beds.

The lower Permo-Carboniferous strata of Kansas and Nebraska are probably also to be correlated with the Artinsk[2] stage, although Waagen[3] classes the entire series with the ammonite-bearing beds of northern Texas, described by Dr. C. A. White in Bulletin 77 of the U. S. Geological Survey. The latter Texas beds, however, belong above the Artinsk stage, and in the true Permian, and are probably of the same age as the middle division of the *Middle Productus* limestone of the Salt Range.

Waagen, in "Salt Range Fossils, Geological Results," p. 238, gives a comparative table, showing the relationship of the upper Paleozoic strata all over the world. While the position assigned some of the American deposits does not agree with that accepted by most American geologists, still the table is useful for comparison, and it has been freely used in compiling the comparative table at the end of this paper.

[1] This horizon is at the top of the Cisco, and above the horizon of *Goniatites marianus.*

[2] KARPINSKY: "Ammoneen der Artinsk-Stufe," p. 92.

[3] Salt Range Fossils, Geological Results, p. 204.

The beds of Poteau mountain, Indian Territory, are probably of the age of the Lo-ping strata of China, while the yellow shales of Scott county, Arkansas, Township 1 N., Range 28 W., Section 4, southeast quarter of southeast quarter, are probably of the age of the Upper Carboniferous limestone of Moscow, and the west slope of the Ural Mountains, if we can judge by the occurrence of *Gastrioceras marianum* and *Pronorites* in them. This would make them older than the Poteau mountain shales, which is very likely the case.

Paleobotanic evidence.—Our knowledge of the paleobotany of the Coal Measures of Arkansas has been up to the present time very limited, depending almost entirely on the publications of Lesquereux, in the "Second Annual Report of a Geological Reconnaissance of the Middle and Southern Counties of Arkansas," 1860, and in the Second Geological Survey of Pennsylvania, Report of Progress, P, "Description of the Coal Flora of the Carboniferous Formation in Pennsylvania, and throughout the United States," 1884.

The joint monograph of H. L. Fairchild and David White, on the "Fossil Flora of the Coal Measures of Arkansas,"[1] throws much new light on the stratigraphic and regional distribution of species, and has been of material aid in correlating the Arkansas strata with those of other regions. They prove that all the Coal Measure plants[2] published from Arkansas belong to the horizon of the Upper or Productive Coal Measures.

The Van Buren plant bed is thought, from paleobotanic evidence, to belong above the horizon from which most of the coal of Arkansas is obtained, that of the Ouita coal, and this agrees with the evidence given by the stratigraphy and the marine fossils. The Van Buren plant bed occurs below the Poteau mountain marine beds, and above those in Sebastian county, Township 8 N., Range 32 W., Section 12; and these latter marine beds occur above the horizon of the Ouita coal.

[1] An unpublished report of the Geological Survey of Arkansas.

[2] The work of the Survey shows that the plants described by Lesquereux from Washington county as Sub-Conglomerate belong to the Lower Carboniferous.

The Poteau mountain marine beds are of about the same age as the Wyoming valley limestones[1] of the Upper Productive Coal Measures of Pennsylvania, and these belong below the Dunkard creek series of the Upper Barren Coal Measures. The Dunkard creek[2] beds have lately been proved by Professor I. C. White to be of the same age as the Permian of northern Texas, on the basis of plant remains that also occur towards the top of the Wichita series of Texas, in which marine Permian fossils[3] have already been found.

But the paleobotanic evidence aids in establishing the age of the Upper Coal Measures only; plants are not reported from any horizons of the Lower Coal Measures, although they are known from a few localities.

Owen[4] mentions *Stigmaria ficoides* as occurring at Patterson's mill, near Bee Rock, on Little Red river, White county. In August, 1892, a few plants were found by the Survey in the Bee Rock sandstone, near the base of the series and below most of the marine fossils, but none of these could be identified.

General D. McRae, of Searcy, informed the Survey that in Township 7 N., Range 7 W., Section 4, in White county, were found shales containing numerous *Lepidodendra* and ferns. These shales are above the Bee Rock sandstones.

In a well at Dr. Griffin's, Township 5 N., Range 10 W., Section 5, near El Paso, White county, specimens of *Lepidodendron* were collected by Dr. J. C. Branner, in micaceous flaggy sandstone, thought to be of the same age as the shales of Searcy. About fifty feet above the flaggy sandstone was found a thin bed of coal, and thirty feet higher was another coal bed with numerous ferns and *Calamites* in the overlying shales.

C. S. Prosser[5] mentions plants supposed to be of Lower

[1] Second Geol. Sur. of Pa., An. Rep., 1885, pp. 437–458, C. A. Ashburner and A. Heilprin, "Report on the Wyoming Valley Limestone Beds."

[2] Bul. Geol. Soc. America, Vol. III., p. 217.

[3] Dr. C. A. White, Bulletin 77, U. S. Geological Survey.

[4] Second Geol. Recon. Ark., Vol. I., p. 68.

[5] Ark. Geol. Survey, An. Rep., Vol. III., 1890, p. 423.

Carboniferous age, from Shinall mountain. In quarries in the sandstones of Big Rock, near the city of Little Rock, are found plant remains of indeterminable character. The stratigraphy of the Survey places both localities in the Lower Coal Measures, and probably above the fossiliferous sandstones of Bee Rock, on Little Red river.

THE PACIFIC CARBONIFEROUS SEA.

Revolution in Devonian time.—In Paleozoic times there have been many revolutions and alternations of continents and seas, and consequent readjustment of their inhabitants to new surroundings. One of the greatest of these was that which broke up a large zoölogical province, and put in direct connection regions that before were separated.

Dr. A. Ulrich [1] has shown that in lower and middle Devonian the faunas of Bolivia, Brazil, the Falkland Islands, and South Africa were very similar to those of North America, and that they were very different from the faunas of Europe and Asia. This state lasted until the end of the middle Devonian, when the revolution began. Professor H. S. Williams [2] has shown that with the beginning of the upper Devonian in America there came in a fauna, many species of which were not the direct descendants of those immediately preceding them. This new fauna was, however, closely related to forms known in Europe and Asia, but unlike those of the southern regions.

Professor Williams [3] afterwards elaborated this theory, and followed out closely the changes that were inaugurated towards the end of the Devonian. The culmination of these changes produced the Pacific Carboniferous sea.

The Carboniferous sea.—From chapter V., in Suess' "Antlitz der Erde," Vol. II., we get many valuable suggestions as to the outlines of the Pacific Carboniferous ocean. The Subcarbonifer-

[1] Beiträge zur Geologie und Paläontologie von Südamerika, I., "Paläozoische Versteinerungen aus Bolivien."

[2] Bull. Geol. Soc. America, Vol. I., "The Cuboides Zone and Its Fauna.

[3] Proc. Amer. Assoc. Adv. Sc., 1892, Section E, Address, "The Scope of Paleontology and Its Value to Geologists."

ous was the time of greatest transgression of sea over the present land areas, while the sea in which the *Fusulina* beds of Europe and America were formed was more circumscribed.

The Waverly group when traced towards the west gradually takes on the character of deep water formations ; it is persistent through Nevada and California,[1] and is known, from unpublished investigations, to have a similar fauna in these two states. The Waverly probably persisted much longer in the west, than in the east, for in northern Missouri C. R. Keyes[2] has observed that in the midst of an undoubted Burlington fauna a well marked Kinderhook or Waverly fauna reappears. This he explains by Barrande's theory of colonies. It is probably an incursion of the inhabitants of a deeper western sea, where the Waverly had persisted longer, into the shallower eastern waters. The work of the Geological Survey of Arkansas shows that a similar phenomenon occurs in that state. The Fayetteville shale, which is probably of Keokuk age, contains a fauna that differs markedly from those of the limestones above and below it. An unpublished report by Professor Henry S. Williams shows the occurrence in the Fayetteville shale of several species that occur in a doubtful upper Devonian or lower Carboniferous black shale in the White Pine district, Nevada. Along with these Devonian or Waverly species occur others that belong much higher, as *Productus semireticulatus*, and *Goniatites* conf. *sphæricus*. Below the Fayetteville shale is the Boone chert, which at the base contains a decided Burlington fauna, and at the top probably belongs to the Keokuk. This has been observed in so many places that there is no possibility of mistake in the sequence of the strata.

We have therefore in Arkansas an incursion similar to that in Missouri, except that in Arkansas the incursion came considerably later. This is evidence that somewhere in the west the Waverly fauna persisted throughout the Burlington, and at least a part of the Keokuk. This is in accordance with the phenomenon described by Professor C. D. Walcott in Monograph VIII.,

[1] Zoe, Vol. III., p. 274; Proc. Calif. Acad. Sci., Oct. 17, 1892.

[2] American Journal of Science, December, 1892, p. 447.

U. S. Geological Survey, from the Eureka district, Nevada, where a Waverly fauna occurs 3000 feet above the base of the Carboniferous formation. The same thing has been observed by the writer in the Carboniferous of Shasta county, California.

The Lower Carboniferous limestones can be traced all through the west and the Mississippi Valley, to the base of the Appalachian Mountains, where they are replaced by conglomerates and other coarse sediments.

Upper Carboniferous in the West.—Of the Upper Carboniferous all that we know west of Indian Territory takes on a decidedly marine character, containing thick beds of limestones.

There are however some thin beds of coal in Texas, and some carbonaceous seams with a few land plants in New Mexico and Nevada. The coal in Texas was probably deposited near the southern shore line of the Carboniferous sea, and the carbonaceous seams in the far west probably belong to insular areas.

The fossils described from the Western Carboniferous are all marine, with the slight exception that Walcott[1] mentions a few specimens of pulmonate *Gasteropoda*, that were found along with brachiopods, corals, and land plants, evidently washed in from a distance, since no terrestrial Carboniferous deposits are known near the Eureka district.

The Pawhuski limestone.—In the eastern part of Indian Territory are found large deposits of coal in the Upper Coal Measures, but further west the same horizon is represented by marine limestone. In 1892 Mr. H. C. Hoover, of the Geological Survey of Arkansas, found at the government lime-kiln, three miles northwest of Pawhuski, Oklahoma Territory, Osage Agency, a bed of massive limestone about 100 feet thick, lying horizontally on heavily bedded sandstones. The limestone is fossiliferous, but the sandstones are not. The fossils collected were placed at my disposal, and on examination they proved to be:

Spirifer cameratus Morton.

Athyris subtilita Hall sp.

Productus semireticulatus Martin sp.

[1] Mon. VIII., U. S. Geol. Survey, p. 262.

Productus nebrascensis Owen.

Productus longispinus Sowerby.

Streptorhynchus crassus Meek and Hayden.

These are plainly of Upper Carboniferous age. The limestones cap the hills in that region, and spread over a great area, but fossils were collected at this place only.

Interchange of life between East and West.—The many beds of marine fossils in the Productive Coal Measures are simply transgressions from the western sea, and reach no further east than Pennsylvania and West Virginia. The Appalachian system was the western border of the ancient Atlantis[1] which separated the European from the Pacific waters, while the great Indo-Australian[2] continent bounded the Pacific ocean on the south. This ocean must have stretched from the American Coal Measures to eastern China, the Salt Range in India, the Ural Mountains on the borders of Russia, and into the Arctic regions, for we find related faunas in all these places. Whatever we have of western European Coal Measure species must have migrated from this direction, since on the east there was no direct communication with European waters. An example of this is *Productus giganteus*[3] Martin, which is common in Europe, and is found in the Lower Carboniferous of the McCloud river, Shasta county, but is not found east of that place, unless *P. latissimus* Sowerby, from Montana, west of the main chain of the Rocky Mountains, be an equivalent.

On the other hand, many species seem to be confined to, or characteristic of, this ocean; among them may be mentioned *Productus cora* d' Orbigny, which Waagen[4] says is not found in Europe, its nearest representative being *Productus riparius* Trautschold; it was however first described from South America.

Goniatites marianus Verneul is found in the Artinsk region of

[1] SUESS: Antlitz der Erde, II., p. 17.

[2] SUESS: Antlitz der Erde, II., p. 316.

[3] See Annual Report U. S. Geog. and Geol. Surv. Terr. 1883, Part I., p. 132, and Bull. Geog. and Geol. Surv. Terr. Vol. II., No. 4, p. 354.

[4] Pal. Indica, Salt Range Fossils, Brachiopoda, p. 677.

the Urals, probably in Sumatra, and in Arkansas. The genus *Pronorites*, while found in western Europe, is rare in it, and is much more common in the Pacific region. *Pronorites* is found in the Artinsk region and in Arkansas, while the ammonite genus *Medlicottia*, the direct descendant of *Pronorites*, is found in the Permo-Carboniferous strata of Sicily, the Urals, the Salt Range, and Texas.

It is impossible to suppose that the same genus and species originated at different localities, and since we have both ancestors and descendants in places so widely separated, we can only suppose that there was free interchange of life between those places at that time, or in other words an open sea, on the borders of which these fossiliferous deposits were laid down, and through which the cephalopods and other marine animals could migrate.

Replacement of Limestones by coal-bearing formations in western Europe.—On tracing the Upper Carboniferous deposits of the Ural region towards the west, we find the limestones thinning out, and the Coal Measures and Culm formations taking their places; we find also that the transgression of marine on terrestrial deposits takes place from the east, just the reverse of what is seen in America.

Land areas in the West.—It is not thought that the Pacific Carboniferous sea was an unbroken expanse of water in western America; on the contrary there are many evidences of large isolated land areas and archipelagos.

Dr. Joseph Le Conte[1] has argued that the Basin Range, during much of Paleozoic and Mesozoic time, was a continent, off the western shores of which the sediments that afterwards became the Sierra Nevada and Coast Range were laid down. Clarence King[2] thought that the great thickness of Paleozoic littoral deposits in the Great Basin region proved the existence of a large body of land further west; he thought that the eastern shore of this continent was in Nevada, and east of this stretched the Carboniferous sea, which covered all but the island chain of the Rocky moun-

[1] American Journal of Science, III., Vol. 16, p. 108.

[2] U. S. Geol. Explor. Fortieth Parallel, Vol. I., p. 534.

tain region. King[1] further concluded that the Carboniferous in California, west of the old shore line, indicated shallow bays that permitted the western extension of the upper Paleozoic deposits, while the bulk of them was stopped by the bold coast. There are evidences of land areas in the Rocky mountains, Wahsatch mountains, New Mexico, and Nevada, but from the facts now known it seems more probable that these were large islands or archipelagos, rather than continents.

THE PERMIAN PACIFIC OCEAN.

The outlines of the great western ocean can be traced in Permian times also, but with much more circumscribed limits. Open sea deposits of this age are known in Texas, in the Salt Range, on the west slope of the Urals, on the island of Sicily, and in scattering places in central Asia. In all these the genera are nearly the same, except that the *Arcestes* types are confined to the more southern regions. This similarity indicates plainly a connection of these deposits.

Suess[2] argues that the open sea Permian fauna wandered in from the south, and that the Mesozoic types of *Ammonites* were foreign to the northern regions.

Karpinsky,[3] on the contrary, holds that they were autochthonous, at least in the Ural region, since he could trace the descent of all the *Ammonites*, except the *Popanocerata* from *Goniatites* that were found in the underlying Carboniferous.

As has been already mentioned, the ammonite genus *Medlicottia* is not a foreigner on this side of the Permian Pacific ocean, because its ancestor, *Pronorites*, is found here too.

The Triassic Pacific ocean.—Our knowledge of the Triassic Pacific ocean is based on the work of Mojsisovics, "Arktische Triasfaunen."[4] We find that in this period the American part of the great western ocean has mostly become land, and only on

[1] Op. cit., p. 535.

[2] Antlitz der Erde, II., p. 316.

[3] Ammoneen der Artinsk-Stufe, p. 86.

[4] Mem. Acad. Imper. Sci. St. Petersbourg, Tome 33, No. 6.

the western border of America do we find marine Triassic beds, in Nevada, California, Idaho, and along the Coast region in scattering places from Alaska to Peru.

These deposits, with similar fauna, can be traced on the other side of the Pacific, from New Zealand, Timor, New Caledonia, to Japan and Siberia. This sea stretches out on one side over the Himalayas to the eastern Alps, forming what Neumayr[1] calls the "central mediterranean sea." On the south side the sea stretched up to Spitzbergen, but did not reach the Atlantic region. The Triassic was a continental period for the greater part of the present continents.[2]

After the Trias the outlines of the western ocean had changed entirely, and no resemblance to the original boundaries can be traced.

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[1] Denkschrift Wiener Akad., 1885, "Die Geographische Verbreitung der Juraformtion."

[2] SUESS: Antlitz der Erde, II., p. 147.

CORRELATION TABLE OF THE COAL MEASURES OF ARKANSAS WITH THE PACIFIC CARBONIFEROUS PROVINCE

		Arkansas.	Indian Territory	Texas	Mississippi Valley	Pennsylvania	China and other parts of Asia	Russia and Ural Mts.	India	South America
Permian			Permo–Carboniferous	Wichita Series, with *Medlicottia*, *Popanoceras* *Waageno-ceras*, etc. *Popanoceras parkeri* Beds	Permo-Carboniferous of Kansas and Nebraska	Upper Barren Coal-Measures	Bokhara Cephalopod Beds	Kostroma Permian Artinsk Stage	Productus: Speck. Sand-stone Series; Lime-stones	Itaitúba Beds
Coal-Measures or Pennsylvanian	Upper Coal-Measures	Poteau Mountain Marine Beds Van Buren Plant Beds Fort Smith Marine Beds Ouita Coal Horizon with Plants Boles, Scott County, Beds with *Goniatites marianus and Pronorites*	Productive Coal-Measures Pawhuski Limestone	Cisco	Upper Coal-Measures	Upp. Prod. CoalMeas. Wyoming Valley Lime-stones Lower Barren Coal-Meas.	Marine Beds of Lo-ping Productive Coal-Measures of China	North. Russ. NovaZembla Upper Carboniferous Limestone	Spiti Limestones	Plant Beds
	Lower Coal-Measures	Morrillton Marine Beds Conway County Millstone Grit, with Marine Fossils Big Rock, Pulaski County, Plant Beds El Paso, White County, Plant Beds Searcy, Bee Rock, Marine Beds Searcy, Bee Rock, Plant Beds		Strawn and Canyon Divisions	Lower Coal-Measures	Lower Productive Coal-Meas. Pottsville Conglomerate		Middle Carbon-iferous Lime-stone	Muth Quartz-ites Lime-Stones	
Lower Carboniferous or Mississippian		Lower Carboniferous Limestone	Lower Carboniferous Limestone	Bend Division	Lower Carbonifer-ous Limestone	Mauch Chunk Series	Lower Carbonifer-ous Limestone	Lower Carbonifer-ous Limestone	Crinoidal	

PSEUDO-COLS.[1]

THE French term *col* is gradually coming into use to signify low passes or saddles on the watershed between drainage systems. Its use is very convenient in the discussion of reversed or diverted drainage, particularly that caused by the intrusion of glacial or igneous obstacles. It not infrequently happens that, when a glacier enters the lower part of a drainage basin, it ponds back the waters, and causes them to pass over such a col into a neighboring basin. Sometimes the valley becomes permanently filled with glacial wash and morainic debris to such an extent as to cause the diverted stream to retain its new course after the retreat of the ice. In such cases the stream, in subsequently deepening its valley, forms a trench across the col, which gradually takes on the form of an ordinary valley. In time the col is only represented by a constriction of the new valley and by certain residual features of the old topographic configuration. The floor of the trench across the col obviously assumes the slope of the new stream that caused it, and has its highest part on the up-stream side of the former col. As the trench is cut deeper and deeper, the highest point in the rock floor is gradually carried up stream. It may, in this way, be transferred some distance from the original col and may thus become entirely disassociated from its peculiar topographic relations. If, after this has been done, another glacial invasion takes place and the valley becomes again filled with glacial wash to some considerable height, the transferred summit of the rock floor is liable to lose its obvious connection with the old col and may perhaps seem to be associated with new and misleading topographic surroundings. If, in such a case, the valley debris is penetrated by wells at only a few points, and the investigator ascertains thereby only

[1] Presented in substance before the Geological Society of America at Boston, Dec. 31, 1893.

imperfectly the nature of the trench and the location of the rock summit in its buried floor, he is liable to mistake this obscured rock summit for a true col. It is, in fact, not a col at all in any proper sense. It never has been a watershed, and has never performed the functions or sustained the relations of a true col. As there is frequent occasion to refer to this phenomenon in the discussion of certain regions of reversed drainage along the border of the ancient glacial formations, I propose for it the distinctive name *pseudo-col.* The nature of the phenomenon has been more or less distinctly recognized by many geologists. The purpose of this note is merely to bring it forth into more definite recognition and to supply it with a convenient name which may be used in lieu of the cumbersome periphrastic phraseology now required.

T. C. CHAMBERLIN.

NOTE ON THE ENGLISH EQUIVALENT OF SCHUPPENSTRUKTUR.

IN a paper entitled "On the geological structure of the Housatonic valley lying east of Mt. Washington" (JOURNAL OF GEOLOGY, Vol. I. No. 8), I proposed the term (p. 791) *weather-board structure* as an equivalent of Suess's term *Schuppenstruktur* to describe a structure caused by a series of small compressed overfolds finding relief through dislocation, and resulting in the production of a parallel series of overlapping plates. Mr. Bernard Hobson, of Manchester, England, has suggested to me that the term *imbricate structure* would be better because of its Latin derivation and its use in botanical literature. The two terms are practically identical as regards the idea conveyed, and though the term first suggested would perhaps give a better mental picture to many minds, Mr. Hobson's term would be more readily understood abroad, and has the added advantage of being the English equivalent of Margerie's *structure imbrique.* I should therefore be glad to see *imbricate structure* adopted rather than the term which I at first suggested.

WILLIAM H. HOBBS.

GEOLOGICAL SURVEYS IN MISSOURI.

The first geological survey of Missouri, having for its field of operations the whole state, exclusively, was provided for by an act of legislature just fifty-one years ago. A period of partial surveys by state and national governments had immediately preceded this, and a period of exploration and travel, and of primitive mining, was of still earlier date.

The explorations of Joliet, of La Salle, and of Hennepin, in the last quarter of the seventeenth century, had transformed the Mississippi valley from *terra incognita* to a promising field for adventure or profit, and, with the establishing of a settlement at the mouth of the Mississippi by Le Moyne d'Iberville in 1699, excursions up the river became frequent. In Le Sueur's expedition, in 1700, the existence of Missouri lead ores became known. This served, a few years later, as one of the incentives leading to the settling of the country by the Company of the West under the Crozat patent. From this time to the end of the eighteenth century the lead deposits were almost continuously worked, sometimes on a large scale, but no record of any careful investigation has come down to us from these early days.

With the beginning of the present century and the transfer of the territory to the United States, an era of somewhat closer observation seems to have been inaugurated. Among the earliest papers touching the geology of Missouri is Austin's "Descriptions of the Lead Mines in Upper Louisiana," written in 1804, covering a few pages of the American State Papers.[1] This is almost entirely descriptive of the lead mines of southeastern Missouri, and treats principally of their superficial features and conditions of development. During the next thirty years, a

[1] Public Lands, Vol. I., p. 188. Reprint Report Mo. Geol. Surv. 1873-74, p. 686.

number of similar short, descriptive reports appeared in these volumes.[1]

Between the years 1804 and 1807 the Lewis and Clarke[2] and the Pike[3] expeditions were conducted for the United States government. These expeditions added much to our knowledge of the geography[4] of the country traversed, but their geological results were meagre, and limited to a strip of country adjacent to the lines of travel.

The year 1815 is worthy of note as marking the beginning of the Land Office surveys in the state. These surveys continued until 1850, and supplied an admirable basis for future areal work in geology. Of interest in this connection is the fact that, during the first two or three decades of operations, the surveyors were required to report to the Land Office, along with their other field notes, the presence or absence of mineral on the land traversed. Drusy quartz, known as "mineral blossom," and other superficial phenomena of wide occurrence, were used as criteria, and, as these notes formed the basis for local classification, complaints soon became loud that so much land was being withdrawn from occupation on account of its being classed as "mineral land," that the settling of the country was seriously interfered with. This led eventually to the abandoning of the early, crude attempt at accomplishing some of the objects of a geological survey.

Schoolcraft's well known tours throughout the western country were made between the years 1816 and 1819, and the three volumes[5] of his observations contain much excellent statistical

[1] For specific references see Bull. No. 2, Geol. Surv. of Mo., 1890, Bibliography pp. 46 and 48.

[2] Travels to the Source of the Missouri River. By Capts. Lewis and Clarke, 1809 and 1814.

[3] Expeditions to the Sources of the Mississippi, etc. By Maj. Z. M. Pike, 1810 and 1811.

[4] Reference to the geographical results of this and other early explorations and surveys will be found in a paper by the writer entitled, "The Mapping of Missouri," Trans. Acad. Science of St. Louis, No. 8, Vol. VI., 1893.

[5] Views of the Lead Mines of Missouri, etc., 1819.

Journal of a Tour into the Interior of Missouri and Arkansas, etc., 1821.

Scenes and Adventures in the Semi-Alpine Region of the Ozark Mts., etc., 1853.

and descriptive matter relating to Missouri, and especially to the mines and topography.

The Long expedition of 1819,[1] similar in nature to the Lewis and Clarke and the Pike expeditions, was equally poor in geological results.

In the year 1821, Thomas Nuttal, the botanist, recorded certain observations on the "Geological Structure of the Valley of the Mississippi"[2] in which he alludes to the limestones of the valley and correlates them with Martin's *Petrifacta Derbiensis*. This, as Professor H. S. Williams has already pointed out,[3] is probably the first recognition of "Carboniferous rocks" in the region. Soon after this, in 1822, Dr. Edwin James called attention to the existence of a sandstone in the Ozark mountains of southeastern Missouri, with a clay slate, like the primitive slate of New England, intervening between it and the granite.[4] This was the first suggestion of the presence of Cambrian or Lower Silurian rocks in Missouri.

During the next ten and more years much attention was attracted to Missouri and other Mississippi valley states, through the extension of mining operations, especially in Iowa and Wisconsin. In volume 12 of the *American Journal of Science*, 1827, there are a number of references to mines and descriptions of minerals found.

During the years 1834 and 1835, G. W. Featherstonehaugh made his well known trip through Missouri and other western states.[5] In his reports he frequently refers to the limestones along the Mississippi as of Carboniferous age, and to the abundance of fossils in the exposures between St. Louis and Herculaneum, some of which he has found identical with European

[1] Account of an Expedition from Pittsburgh to the Rocky Mts., etc., 1823.

[2] Jour. Acad. Sci., Philadelphia, 1821, Vol. 2.

[3] Bull. No. 80, U. S. Geol. Surv., pp. 25 and 137.

[4] Jour. Acad. Sci., Philadelphia, 1822, Vol. 2.
Also: C. D. Walcott, Bull. 81, U. S. Geol. Surv.

[5] Geol. Report of the Elevated Country between the Missouri and Red Rivers, 1835.
Reconnaissance to the Green Bay and the Wisconsin Territory, 1836.

forms. From this and other statements it is plain that he did not discriminate between the different limestone formations which we now recognize in the Mississippi valley. He made a special examination of southeastern Missouri, and expresses the conclusion that the disseminated lead ore of Mine la Motte must necessarily have been deposited at the same time as the limestone; also that the veins of this country undoubtedly descend very deep towards the central part of the earth; and, finally, that the ore in these veins was "projected from below," the lateral veins from a main lode being compared to the branches of trap dikes, while the red clay is paralleled by the red mud accompanying volcanic eruptions in Sicily. The iron ores of Missouri, he also states, are of direct subterranean origin and fill veins or fissures produced by dislocation.

Though such ideas seem extravagant to us now, they were discussed and believed by scientific men of the day. Thus, in the proceedings of the fifth session of the American Association of Geologists and Naturalists, after a statement of Professor J. Locke's, that the Trenton age of the rocks containing lead ores of the upper Mississippi had been determined, Dr. Houghton replied that he did not think the ores were confined to any special limestone, but that they had been sublimed and segregated through the heat of intrusive trap. R. E. Rogers expressed himself in support of a similar explanation. In answer to this Dr. H. King sagaciously remarked that no volcanic or igneous action had taken place in Missouri or elsewhere in this lead region, and thus could not have influenced the segregation of the lead; that the subjacent rocks were not traversed by dikes, and that the lead ore was imbedded in the rock, like masses of chert.[1] Again Mr. J. T. Hodge, in 1842, in a long article on the Missouri and Wisconsin-Iowa mining regions, after describing copper deposits of Missouri, concludes that the copper ore had apparently been projected from below, either melted by sublimation or by slower electrical causes.[2]

[1] See Am. Jour. Sci., Series I., Vol. 47, 1844, p. 106.

[2] Am. Jour. Sci., Series I., Vol. 43, 1842, p. 69.

The year 1840 brings us to the date of publication of Owen's report on the Mineral Lands of the United States in portions of Iowa, Wisconsin and Missouri,[1] following closely upon his report as state geologist of Indiana upon work of 1838 and 1839. In 1844, a second and revised edition of his Mineral Lands report was issued, and, in 1852, his final report on Wisconsin, Iowa, and Minnesota appeared. These reports supplied the guiding lines along which later stratigraphic work in the Mississippi valley was done. Without attempting here to present the history of this work,[2] its bearing upon the future work in Missouri calls for brief mention. In the Indiana reports Owen makes a separation of the rocks, in harmony with the English classification, into: (1) Bituminous Coal formation; (2) Mountain limestone; (3) Grauwacke; (4) Crystalline and inferior stratified rocks. In the succeeding reports, as the results of wider observation and more thorough study, the classification was changed and differentiated until, in the final report, we find a classification which, not only in its general features, but in many of its details, is still adhered to in Missouri. The map accompanying this report attempts a representation of the areal geology of the northern half of the state. On this map the western margin, as far east as Wellington, is colored as belonging to the Upper Series of the Carboniferous limestone; along the Mississippi river a similar belt of both the Upper and Lower Series is represented; while, along the Missouri river, from above Jefferson City to Tower Rock, is an area of Lower Magnesian limestone. Between these a broad stretch of Coal Measures is shown.

The explorations and surveys thus far referred to were the results of private enterprise or were made under the auspices of the national government. The earliest record we have of action on the part of the state is in the message of Governor Lilburn W. Boggs in 1833. He there recommends an appropriation for

[1] House Exec. Doc., No. 239, 26th Congress, 1st Session.

[2] For summary concerning the Devonian and Carboniferous, see H. S. Williams, Bull. 80, U. S. Geol. Surv., p. 137 *et seq.*

a geological survey as an adjunct to a general system of internal improvement. Shortly after this a Board of Internal Improvements was formed, and, among other works, surveys of the Meramec, of the Salt, of the North Grande and of the Osage rivers were started. In connection with this, a geological examination by Dr. Henry King was made along the Osage river, and a report of twenty pages was published in 1840.[1]

Much of this report is devoted to the topography and soils, and to a description of occurrences of ore. Dr. King assigns all of the rocks of the region to the Carboniferous formation and separates them into two series: (1) A lower Galeniferous or Lead series; (2) an upper Coal series. By the former he plainly means the magnesian limestones and associated sandstones, though the section given is very imperfect; in the latter he includes the Encrinital or Lower Carboniferous limestones as well as the overlying coal beds, sandstones, and shales. The change between the two series is so marked, however, that he expresses the feeling that an entire separation of the two is almost justifiable. The lead ores of the region he assigns to the uppermost member of the lower series; the surface float ore, or "patch mineral," as he calls it, he determines correctly to be residuary from the decay of the limestone.

After this, further investigations by the state seem to have fallen into neglect for several years; but, by 1846, the subject again excited public attention and the question of a geological survey called forth a number of memorials from conventions, and of papers prepared by scientific associations, and was further recommended in the messages of several governors. Finally, by an act approved February 24, 1853, the First geological survey of Missouri was authorized.[2] The act controlling the First geological survey provided for the appointing by the governor

[1] Senate Journal, Appendix, 1st Session, 11th Gen. Assembly, 1840, pp. 506–525.

[2] Additional information beyond what is given in the following pages, relating especially to the laws governing the various state surveys, their organization, and plans of work, will be found in an historical sketch of Missouri Geological Surveys, forming part of the writer's Biennial Report to the 36th General Assembly, House Journal, 1891.

of a state geologist, who, in turn, was allowed the appointing of not more than four assistants, who were to be skilful chemists, and of such other subordinate assistants as he might deem necessary. The work of the survey was to include stratigraphic and structural geology and special studies of economic geology. Annual reports were required, and a final report, or a complete memoir on the geology of the state, was to be prepared on the completion of the survey. Specimens in triplicate were to be collected and forwarded to the Secretary of State ; one set for a cabinet in the state capitol, another for the state university, and the last for the city of St. Louis. Ten thousand dollars annually for a term of two years were appropriated.

Pursuant to the instructions of this law, Professor G. C. Swallow was appointed state geologist by the governor in 1853. Professor Swallow came directly from Maine, where he had been engaged in teaching. The survey continued in active operation until, June 1861, under the direction of Professor Swallow. The controlling plan of the work as laid down by him, in the letter of transmittal accompanying his second annual report, was to prepare : " First, an outline of the geology of the state ; second, a general view of the mineral wealth of the mining districts ; third, an exposition of the agricultural and manufacturing resources of the state ; fourth, reports in detail upon as many counties as possible."

Five reports were published by this survey, but the second, of 447 pages (with which is printed the first, of but four pages) is the only one which embodies the results of field work, and this is the one generally known as the Swallow report. The others are very brief reports of administration and progress. Part I of this Second Annual Report contains chapters by Professor Swallow on the general geology of the state and two county reports ; Part II contains a chapter by Dr. Litton on the lead mines of southeastern Missouri, and three county reports by Meek and Shumard, as well as several general cross sections and a short paper on paleontology.

After the issue of this report the survey continued in active

operation until 1861, during which time its labors seemed to have been centered upon systematic county work, leading to the production of special county maps and reports. A table contained in the fifth report of progress shows that, up to the end of 1860, field work had been completed in eighty counties, and of these, reports had been made upon thirty-three; in a considerable number of other counties more or less work had been done. Five of these reports were contained in the Second Annual, and twenty more constitute a report issued in 1873; others were probably used in the preparation of the county descriptions of the other reports of 1873 to 1874. In addition to this work, during the period of the first survey, Professor Swallow made an official report of ninety-three pages on the Southwest Branch of the Pacific Railway.

Reviewing, briefly, this work of the First geological survey, we must recognize as remarkable and excellent the classification of the rocks which are evolved, as well as the general accuracy with which the distribution of the formations was defined, especially when the short time is considered; avowedly under the control of Hall's New York classification and nomenclature, published in 1843, though undoubtedly assisted, yet not misled by Owen's results, Swallow and his assistants established a table of formations, and outlined a geographical map of the state which remains to this day unchanged in its larger features.

From 1860 to 1870, geological work was nearly at a standstill in the state. During this period, however, Professor Swallow, as professor of geology at the state university, and various of his assistants in different capacities, extended their observations in the state, and published the results in scientific journals or in the proceedings of scientific societies.[1]

In March, 1870, an act was passed authorizing the Second geological survey. The provisions of this act were in the main similar to those of the first, with the exception that the Bureau was placed under the control of a board of managers of nine

[1] For a Bibliography of the Geology of Missouri, see Bull. No. 2, Mo. Geol. Survey, 1890.

members. The state geologist was allowed to appoint one assistant state geologist, who was required to be a chemist, at an annual salary of $2,000 ; also other subordinate assistants at not more than $1.50 per day. Provision for the appointment by the Board of a state assayer was also made. For the "general expenses" of the bureau the sum of $7,500 was allowed annually Under this law Albert D. Hager, previously of the Vermont survey, was appointed state geologist. The law was amended in March, 1871. The number of the members of the Board was reduced to four, and the allowance for the annual expenses raised to $10,000. Mr. Hager held this position until August, 1871, and published one report of progress, twenty-one pages in length, in which he briefly notices the chief building stones and minerals of the state. After Mr. Hager's resignation, Dr. J. C. Norwood was in temporary charge. In November, 1871, Mr. Raphael Pumpelly was appointed state geologist. He resigned from the position in May, 1873.

Up to the time of Mr. Pumpelly's appointment, very little had been made public of the results of the surveys, and the changes of management must necessarily have retarded and weakened the work. Notwithstanding this, however, Governor B. Gratz Brown, in his message of December, 1871, commends the survey warmly to the Legislature, and, as a result, the law was amended in the following March, and the sum of $20,000 was appropriated annually for the salaries and expenses of the Bureau.

Two classes of work were provided for in the Pumpelly survey, *i. e.*, (1) the study of the stratigraphy of the state; (2) the study of the mineral deposits. The stratigraphic work was divided into five departments covering different sections of the state; that of economic geology was divided into three, including a department of iron ores and metallurgy, a department of ores other than iron, and a department of fuels and materials of construction other than iron and wood. Under the Pumpelly management two reports were issued in 1873. The first was an octavo of 323 pages, already referred to as containing twenty

county reports, prepared during the Swallow survey.[1] The second volume was a large octavo of 655 pages[2] transmitted in April, 1873. Part I consists, first, of a chapter on the geology of Pilot Knob and vicinity by Mr. Pumpelly; the second chapter embodies analyses of ores, fuels and pig irons; chapters III to IV, inclusive, constitute a partial report on the iron ores of Missouri by Dr. Adolph Schmidt. Part II consists of fifteen chapters and three appendices; of these, chapters I to VI contain general information relating to the coal fields of the state by Prof. G. C. Broadhead; chapters VII to VIII are on the geology of Lincoln county by Prof. W. B. Potter; chapters IX to XV consist of reports on seven counties by G. C. Broadhead; appendices A, B and C relate to building stones and contain a list of Coal Measure fossils.

After Mr. Pumpelly's resignation, Prof. G. C. Broadhead was appointed state geologist and assumed charge in July, 1873. During this administration the examinations of the iron ores and of the lead and zinc deposits were continued, and surveys for a number of county reports were made. One volume was issued by the Broadhead survey.[3] This is a large octavo of over 790 pages transmitted in August, 1874. Chapters I to VI, inclusive, are upon general topics relating to the history of exploration and the general geology of the state by Professor Broadhead; chapters VI to XXI, inclusive, consist of reports on fifteen counties; chapters XXII to XXXII, inclusive, and XXXIV, describe the lead and zinc deposits of the state from work done by Dr. Schmidt and Mr. A. Leonhard; chapters XXXIII and XXXV relate to the iron ores of southeastern

[1] Reports on the Geological Survey of the State of Missouri, 1855–1871, by G. C. Broadhead, F. B. Meek and B. F. Shumard, Jefferson City, 1873, pp. 324 and iv.

[2] Geological Survey of Missouri, Raphael Pumpelly, Director. Preliminary Report on the Iron Ores and Coal Fields, from the field work of 1872, with 190 illustrations in the text and an atlas. New York: Julius Bien, 1873. P. xvi., 214 and 441.

[3] Report of the Geological Survey of Missouri, including field work of 1873–74, with 91 illustrations and an atlas. Garland C. Broadhead, State Geologist, Jefferson City, 1874. Pp. 734, L. 4, 50.

Missouri. Appendices A, B, C and D contain much statistical and other matter of subordinate interest.

The survey was discontinued after the year 1874, and most of its working material was transferred to the state School of Mines at Rolla, of which the president, Dr. Charles P. Williams, was made acting state geologist, with a nominal appropriation. Little field work seems to have been carried on under Dr. Williams, and, after the year 1876, no further support was extended to the work by the state. One report was prepared by Dr. Williams, which consists of a small octavo of 117 pages. It contains a chapter on the "Mineralogy and General Metallurgy of Lead," one on the "Zinc Industry of Missouri," one on the "Iron Industry," and one on "Shannon County"; in the appendices are given a few statistics of lead and zinc, and a "Note on the Occurrence of Gold in Northwestern Missouri."

Reviewing the results of the Second geological survey, its contribution to our knowledge of the geology of the state consisted principally: (1) of Pumpelly's observations, too soon interrupted, upon the crystalline rocks, whose work threw much new light upon their nature and relations, though the report has left us in some doubt as to whether he considered the whole mass of the porphyries metamorphosed clastics, or whether he meant this to apply only to the Pilot Knob beds; (2) of Broadhead's detailed stratigraphic results in the Coal Measures which placed on record many new and valuable sections, added much concerning their correlation, and demonstrated the thickness of this formation to be much greater than had been formerly believed; (3) of Schmidt's report on the iron ores and lead and zinc deposits, especially strong in its treatment of the mineralogy, but deficient in its interpretations of structure, and lacking in suggestions as to origin and processes. The classification of the clastic rocks remained substantially the same as tabulated by Swallow and Shumard, the principal changes displayed in the chart opposite page 18 of the report of 1873–74 being in the subdivisions of the Lower Carboniferous; in the transference of the Chouteau, Vermicular and Lithographic stages to this series; and

in the assignment of the Third Magnesian limestone and all below it to the Potsdam period.

Summarizing the products of both the First and Second surveys, we find that there were published six volumes, varying in length from ninety-three to over 700 pages, and four pamphlets, aggregating about fifty pages. The appropriations for these two geological surveys, as given by Broadhead.[1] are as follows:

	APPROPRIATIONS.	EXPENDITURES FOR PRINTING.
From 1853 to 1862 - - -	$105,000	$5,000
1870 and 1871 - - -	12,500	
Under acts of 1872, 1873 and 1874	60,000	19,320
In 1876 and 1877, and by School of Mines - - - -	5,000	1,500
Printing, 1873 - - - -	12,000	
Printing, 1876 - - -	1,500	
Total - - - -	$196,000	$25,820
Unexpended appropriations -	19,814[2]	
Total expended - -		$176,185
Balance for salaries and current expenses - - - -		150,365

After the stoppage of the apology for a geological survey, for which provision was made under Professor Williams' control, no public geological work was conducted until the year 1884, when topographic work was begun in the state by the United States geological survey. This was continued until July, 1889, up to which time about one-third of the state was mapped on sheets of a scale of two miles to the inch, and with contour intervals of fifty feet. In addition Mr. W J McGee was detailed in 1887, by the national survey, to make a brief study of the geology of a portion of Macon county, the results of

[1] Missouri Geological Surveys. Historical Memoir. Trans. Acad. Sci. of St. Louis. Vol. IV. Pp. 611–614.

[2] We are informed by Professor Broadhead that the larger part of this unexpended appropriation belonged to the period of the Swallow Survey, though part of it also reverted during the Hager administration of 1870 to 1871.

which are published in Vol. V. of the Transactions of the St. Louis Academy of Science.

In May, 1889, the act authorizing the present, or Third geological survey, was approved. It was evidently framed upon the laws of the preceding surveys, though it differed from them in detail. The most noticeable differences are the absence of a requirement to collect specimens in triplicate, and the absence of a clause requiring county maps and reports to be prepared. The state geologist is, however, directed to have complete and detailed maps and reports of counties or districts prepared. The appropriation for the two years, 1889 and 1890, was $20,000; that for 1891 and 1892 was $40,000; out of this all salaries and expenses were to be paid, including cost of publication. For the years 1893 and 1894, $20,000 have been appropriated, though the paper for publications is furnished in addition.

The writer was elected state geologist in August, 1889, and entered upon the discharge of his duties the end of September following. The plan of work adopted for this survey was: (1) to prepare a series of monographic reports upon separate subjects, which may be called Subject reports, applying to the whole state; those subjects of direct economic importance to receive first consideration; (2) to prepare successively a series of detailed maps of different portions of the state, and to accompany these with special reports containing much descriptive detail, which we may call Area or Sheet reports.

The subjects of work so far undertaken have been: the lead and zinc deposits; the coals and the Coal Measures; the clays; the iron ores; the mineral waters; the building stones; the crystalline rocks; the Quaternary, or, more exactly, the glacial geology; the paleontology; the hypsometry; general geologic mapping. Work has advanced on all of these subjects to varying extents. The study of the lead and zinc deposits was begun in coöperation with the national geological survey, but has been carried to completion by the state survey, and the report is now nearly finished. A Preliminary Report of 226

pages on the Coals of the state, by the writer, has been issued, but a great bulk of additional information has been gathered for a final report. The field work for the report on Clays was finished last year, and the report, by Prof. H. A. Wheeler, is now well advanced. A report on the Iron Ores of 391 pages, by Frank L. Nason, was published in 1892, together with one of 280 pages on the Mineral Waters, by Paul Schweitzer. The building stones were studied first by G. E. Ladd and later by Hiram Philips, but the field work is not yet completed, and had to be suspended this year. The crystalline rocks were studied by Erasmus Haworth and the report is written, but is withheld from publication for lack of funds. Field work for a preliminary report on the glacial geology, by J. E. Todd, was completed last year, and the report will soon be ready for transmission. An exhaustive review of the paleontology of the state by Charles R. Keyes is ready for publication. All available data relating to the hypsometry of the state have been collected and tabulated, and a few months additional work will put them in shape for publication. Along with the prosecution of work on these general subjects, many additional facts for more exact and detailed geological mapping have been collected; but in addition to this, mapping of the formations has been specially done over certain important areas of the southwestern and northeastern portions of the state.

For the Area or Sheet reports, fifteen sheets have been prepared, distributed over the central portion of the state along the margin of the Coal Measures, over the southwestern lead and zinc district, and over the southeastern lead district and Archean area. These sheets are on a scale of one mile to the inch with a twenty-foot contour interval, and cover each a quadrilateral of fifteen minutes of latitude and longitude. They include, in addition to the topography and general geology, much detail of special economic importance. Three of these sheets have been engraved, and the accompanying reports printed. The others are about ready for the engraver, and the reports are partly prepared.

Summarizing the official publications of the Third survey to date they are as follows:

Reports published:

Vol. I. A Preliminary Report on Coal, 8vo, 226 pages; Vol. II. Report on Iron Ores, 8vo, 391 pages; Vol. III. Report on Mineral Waters, 8vo, 280 pages; Five Bulletins, including a Bibliography of the Geology of Missouri, and articles on the coals, building stones and clays, mineral waters, crystalline rocks, and paleontology, aggregating 470 octavo pages. Also two administrative Biennial Reports aggregating 90 pages.

Three sheets and accompanying reports as follows: No. I. Higginsville Sheet and large folio report, 18 pages; No. II. Bevier Sheet and octavo report, 90 pages; No. III. Iron Mountain Sheet and octavo report, 96 pages.

Reports completed but not published:

Report on Paleontology, 400 8vo pages (estimated); Report on the Crystalline Rocks, 300 pages (estimated).

Reports nearly completed:

Report on Lead and Zinc Deposits, 500 8vo pages (estimated); Report on Clays, 400 8vo pages (estimated); Report on Quaternary Geology, 150 8vo pages (estimated); Report on Hypsometry, 150 8vo pages (estimated).

Reports only partly prepared:

Final Report on the Coal Measures; reports on twelve sheets of detailed mapping.

ARTHUR WINSLOW.

EDITORIALS.

THE doctrine of isostasy has been tentatively accepted by many working geologists. It finds application in various departments of geology, but nowhere more conspicuously than in glaciology. Without passing judgment on the doctrine, and without attempting to restrict the field of its application, attention is called to a misapprehension to which it has given rise. This misapprehension is widespread in the popular mind, and has even found a foothold among those who have given attention to glacial geology.

Among the hypotheses which have gained more or less currency in explanation of the Pleistocene glacial climate, is that of northward elevation. Whatever may be thought of this hypothesis from *a priori* considerations, or whatever may be thought of the evidence which is adduced in support of it, it has come to have an appendix which we believe to be false. This appendix seems not to have accompanied the hypothesis at the outset, and some of the advocates of the hypothesis do not appear to have given their sanction to the appendix, though their names are sometimes connected with it.

The hypothesis is, that northward elevation lowered the temperature of the region affected to such an extent as to occasion the accumulation of the Pleistocene ice-sheet. The appendix is, that the elevated area sank under the weight of ice for which it was responsible, until, as a result of the sinking thus effected, the climate was so far ameliorated as to bring about the melting of the ice-sheet and the end of the glacial period. The appendix is sometimes stated in milder form, the depression resulting from the weight of the ice being looked upon as only one of the causes which brought about the dissolution of the ice-sheet. This view, both in its wider and in its more restricted sense, we

believe to be without foundation. Its fallacy appears when the quantitative elements of the problem are considered.

Let it be assumed that northward elevation was the cause of the cold climate which made the development of the Pleistocene ice-sheet possible. Let it be assumed further (and this is the assumption most favorable to the doctrine here opposed), that the elevated region was in isostatic equilibrium at the time the ice began to accumulate. Let it be assumed also, that the average specific gravity of the mass of snow and ice of the ice-sheet was one-third that of the rocks of the earth's crust. On the doctrine of isostasy, depression should have accompanied the accumulation of snow and ice. When the central part of the snow-field had a depth of 300 feet, the maximum depression which it could have caused, under the assumed conditions, was 100 feet. At the minimum, therefore, the surface of the central part of the ice-field must have been 200 feet higher than the surface of the land before the ice-field formed. Nearer the margins of the ice-field, where the ice was thinner, both the depression of the land surface and the accompanying elevation of the snow surface would have been less; but each point of the surface of the snow-field must have been higher than the corresponding point of the surface of the land at the time the ice began to accumulate, and the temperature at all points must have been correspondingly reduced. Instead of being ameliorated by the depression of the land surface, the very conditions which brought about this depression were causing the climate to become progressively more severe. When the ice had attained a thickness of 3,000 feet, it might have occasioned a maximum depression of the subjacent land surface to the extent of 1,000 feet, and therefore a minimum elevation of the ice surface at the same point, to the extent of 2,000 feet. While, as before, both the depression of the subjacent land surface and the correlative elevation of the surface of the ice-sheet would have been less near the margins of the snow-field than at its center, it still remains true that each point of the entire surface of the ice must have been higher than the corresponding point of the surface of the land at

the time the ice began to accumulate, and higher than the corresponding point of the surface of the ice at every earlier stage. When 3,000 feet of ice had accumulated, and when this body of ice had caused its full measure of depression, the temperature over it must have been reduced at each point by an amount corresponding to the actual increase of elevation of the snow surface over the pre-existent land surface at that point. The force of the point here made is in no way lessened if the depression caused by the accumulation of the ice lags behind the accumulation itself. In so far as the sinking lags behind the loading, the temperature of the surface is reduced beyond the limits indicated. The principles here referred to will neither be reversed in their operation, nor rendered nugatory, by further accumulation of ice. So long as the ice thickens, it will remain true at all times that each point of the surface of the ice-field must be higher than the corresponding point at any earlier stage in the process of accumulation, isostasy alone being considered. The elevation of the ice surface (and this is the surface which determines the climate), will overbalance any depression of the land surface which the ice can cause by the disturbance of isostatic equilibrium. There is, therefore, not only no tendency to the amelioration of climate as the result of excessive snow accumulation, but there is a constant reduction of temperature. Whatever may have caused the dissolution of the Pleistocene ice-sheet, it was not the amelioration of climate resulting from the depression caused by the weight of the ice itself, under conditions of isostasy. R. D. S.

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WITH this number, THE JOURNAL OF GEOLOGY begins the publication of a series of articles on the geological surveys of the various states of the Union. These articles will be prepared, so far as practicable, by the official geologists of the several states. Their purpose is to publish to the geological world the present condition of geological work in the various regions with which they deal. They will indicate what has been done, and by whom. They will make known the various plans on which survey work has been prosecuted in the several states. They will

state the problems which still remain to be solved, and something of their relative importance. They will bring out the scientific and economic advantages which have resulted, directly or indirectly, from the surveys already executed. They will indicate the general scope of the more important publications, both cartographic and textual, which have appeared, and while they are not intended to be bibliographic primarily, they will contain references to the more important publications and to such bibliographies as may have been compiled. In some cases, at least, they will give the cost of the work which has been accomplished. The plan also involves a series of articles on the surveys in foreign countries. It is hoped and believed that these papers will be of much value. A considerable period of time will necessarily elapse before the series is completed, but in the end it is believed that it will constitute a valuable compendium of geological work throughout the world.

R. D. S.

Reviews.

The Economic Geology of the United States. By R. S. Tarr, Assistant Professor of Geology at Cornell University. 8vo, 509 pp. Macmillan & Co., 1894.

This volume discusses the ore deposits and other minerals and rocks of commercial value found in the United States, as well as a few of the foreign deposits of a similar nature. The book is divided into three parts. Part I. treats of the general mineralogical, geological and technical subjects more or less directly related to the various mining industries. It gives, first, a chapter on "Common Rock and Vein-Forming Minerals," followed by chapters on the "Rocks of the Earth's Crust," the "Physical Geography and Geology of the United States," the "Origin of Ore Deposits," and "Mining Terms and Methods." Part II. treats of "Metalliferous Deposits," including the ores and deposits of the useful metals. Part III. treats of the "Non-metallic Mineral Products," such as coal, petroleum, fertilizers, building stones, etc. In addition, the volume also contains a short appendix on the "Literature of Economic Geology." The object of this volume, as stated by the author in the preface, is to supply the pressing need of a text-book to accompany a series of lectures given by him to a class of students in economic geology at Cornell University.

The book is beautifully printed and neatly bound. The illustrations are well reproduced, and, in fact, all of the publishers' work on the book is very good and reflects credit on Macmillan & Co. The book is written in good language, and the general scheme in the arrangement of the subject matter is logical, but the text is deficient and contains many erroneous statements. The chapters on the "Rocks of the Earth's Crust" and on the "Physical Geography and Geology of the United States," give a fair general idea of those subjects, although even here there are a number of inaccuracies. The chapter on "Common Rock and Vein-Forming Minerals" and parts II. and III. of the book, treating of "Metalliferous Deposits" and "Non-Metallic Mineral Products," however, relate more especially to economic geol-

ogy, and are the essential features of the volume. They, therefore, deserve consideration in some detail.

The most important feature of a book of this kind is the discussion of ore deposits, yet at the outset a faulty definition of the term "ore" is given. The author says, on page 15, "an ore may be defined as a mineral with a metallic base." Unless further qualified, this definition is, to say the least, vague, for though all ores have metallic bases, there are a number of important minerals with metallic bases which are not ores. Thus, oxide of iron, sulphide of lead, sulphide of copper and other materials have metallic bases, and under proper conditions are ores; but gypsum, calcite, baryta, mica, and many other minerals have metallic bases and are not ores. Moreover, though many ores are minerals, many others are not minerals at all, but are common rocks having some special metallic constituent as their only unusual feature. Thus the ore of the Calumet and Hecla copper mines is a cupriferous conglomerate, the Mansfeld copper deposits of Germany are cupriferous shales, and many other similar instances might be mentioned. The author adds that, "properly speaking, the metallic constituent should be a predominant constituent." Though in some ores the metallic constituent is a predominant one, yet in some of the most important ores the metal forms only a small, and often an insignificant, constitutent. In most gold ores the metallic constituent forms but a fraction of one per cent. of the ore, and in most silver ores the silver forms but a slightly larger amount. In copper deposits, the copper rarely forms a large percentage of the ore, and in many other cases the metallic constituent is entirely subordinate.

The author states that "the miner considers an ore to be a mineral with a metallic base, occurring in sufficient abundance to be economically valuable; but from the scientific standpoint, a grain of magnetite in a granite rock is as much an ore as a bed of this mineral." The term ore is essentially a technical mining term, and has no scientific significance whatever. When a metal can be profitably extracted from a certain material, that material becomes an ore; but other materials may contain just as much of the same metal, and yet, on account of their mineralogical or other features, they may not be commercially profitable sources of the metal, and then they are not ores. Whether a material is an ore or not, is dependent on commercial conditions, which may vary from time to time; and this very fact prevents the term from having a scientific meaning.

On page 16 the author says that "the group of silicates is extremely large, including many of the important rock-forming minerals, but as ores they are of little importance." He has evidently overlooked the fact that calamine, a hydrous silicate of zinc, is an important ore, and that garnierite, a hydrous silicate of nickel and magnesia, is the source of a large part of the nickel of commerce. The latter is the ore mined at New Caledonia, off the coast of Australia, one of the two largest nickel producing regions in the world. It also occurs in the United States. The author again overlooks this silicate when, on page 26, in enumerating the ores of nickel, he says, "nickel is obtainen from the two sulphides, millerite, niccoliferous pyrrhotite, and the arsenide niccolite." In other deposits also silicates form a minor but an important part of the ore, as in the case of chrysocolla in the copper ores of Arizona.

On page 18 the author states that, "Sometimes, though not commonly, gold occurs in iron pyrites in invisible grains." It is almost unnecessary to say that one of the most common modes of occurrence of gold is in intimate association with iron pyrites, so that this statement is extremely misleading.

On page 20 the author says: "Gold occurs in the earth in only two mineralogical forms, so far as known, one in association with tellurium, the other native, the latter being its typical occurrence and the one from which the gold in use is obtained." It is true that native gold is the source of most of the gold in use, but the telluride ores, far from producing no commercial gold, are in many mines an important source of that metal. At Cripple Creek, in Colorado, the tellurides form an important part of many of the ores, and this district produced between \$2,500,000 and \$3,000,000 in gold in 1893. In Boulder county, Colorado, tellurides are also of importance, and have been so for many years past, while tellurides frequently occur in still other places.

On page 22 the author, in speaking of copper, says: "Its most common occurrence, however, is as the sulphide, *chalcopyrite* ($CuFeS_2$), or copper pyrites, which is in reality a sulphide of iron and coppes combined, the proportion varying from an exceedingly cupriferous variety (chalcopyrite) to pure iron pyrites." The sulphide of copper known as copper pyrites is a definite chemical compound, with proportions of iron and copper in a definitely fixed ratio, so that the mineral cannot vary from an exceedingly cupriferous variety to pure iron pyrites. The same may also be said of other sulphides of copper.

Copper pyrites is often, and even usually, when found in nature, mechanically mixed with iron pyrites, and the relative amounts of copper pyrites and iron pyrites in a deposit may vary considerably. Different analyses of this mixture of the two minerals may, therefore, show varying proportions of copper and iron, but the composition of the copper pyrites itself is constant.

On page 23 the author speaks of the "pale yellow rust" of lead ores, and by "rust" he means doubtless the carbonate of lead formed by the action of surface agencies on the superficial parts of certain lead deposits. This product is often stained yellow or brown by the oxidation of iron pyrites, which is frequently associated with galena, the common ore of lead; but the normal color of the "rust," or carbonate of lead, is white. An oxide of lead of a yellow color may be formed when certain lead minerals are highly heated under suitable conditions, but this process would obviously be a very unusual one in nature, and the common product of the superficial alteration of galena ores is first the sulphate and then the carbonate of lead.

On page 132 the author, in speaking of iron ores, says: "The carbonate, siderite, may be considered to be a combination of iron and calcite in which the percentage of iron varies even to the point of complete replacement of the calcium." Siderite is a definite chemical compound containing iron protoxide and carbonic dioxide in fixed proportions, while calcite is also a definite chemical compound containing calcium oxide and carbonic dioxide in fixed proportions. Both siderite and calcite are isomorphous carbonates, and the two crystallize together in various proportions. The carbonate of iron, however, can in no way be called a "combination of iron and calcite."

The Lake Superior copper and iron districts, which, taken together, form one of the most important mining regions in the world, are discussed very briefly, but even the descriptions given are inaccurate. On page 210, in speaking of the Lake Superior copper ores, the author says that "in some of the mines, mineralized ores of copper are the source of the metal, but the most common ore is native copper frequently associated with native silver." The fact is that none of the copper produced in the Lake Superior region is derived from "mineralized"[1] ores of copper, but all of it is obtained from native copper. The native copper is sometimes slightly stained green by the forma-

[1] By "mineralized ores" it is supposed that the author means the ores in which the copper is combined with other elements, forming sulphides, carbonates, oxides, etc.

tion of a thin crust of carbonate of copper on its surface, but even this does not always happen, and one of the remarkable features of the Lake Superior region is the very extensive occurrence of copper in its native state. Copper sulphides are disseminated through the region, and are probably the source from which the native copper was derived in nature; but they have not been found to be themselves concentrated in commercially important quantities, and are therefore not mined. Small quantities of oxide of copper also occur, but are likewise not of present importance.

On page 125 Professor Tarr, in describing a section by Van Hise, showing the mode of occurrence and formation of the iron deposits in the Penokee-Gogebic range in the Lake Superior region, states that Irving and Van Hise have shown that the hematite deposits of that region were formed by a replacement of "beds of dolomitic limestone." It may be said here that the iron deposits of the Penokee-Gogebic range occur in the Upper Huronian series, which, in this district, contains no dolomitic limestones. A dolomitic limestone occurs near the base of the Lower Huronian of the district, but it has no connection whatsoever with the Penokee-Gogebic iron deposits. Van Hise clearly states, in his various publications on this subject, that the iron deposits of the Penokee-Gogebic range represent a replacement of a siliceous rock containing carbonate of iron and other carbonates, and designated by him as cherty iron carbonate. One of the principal points which Van Hise brings out in the discussion of his theory for the formation of these deposits is that the change has been largely an oxidation of the iron carbonate and a replacement of silica by oxide of iron. Professor Tarr also gives a geological section illustrating the occurrence of the Penokee-Gogebic ores, and designated by him as "modified from Irving and Van Hise." In the legend below the section, the iron deposits are referred to as "iron ore, replacing ferruginous chert"—a statement not at all in accord with Professor Tarr's text just cited. It is, moreover, difficult to understand on what basis an author, who has never studied a region, has "modified" the geological sections of other authors who have spent years in investigating that region.

The errors in this book that have already been pointed out are only a few among the many that might be mentioned, but they serve to show the want of familiarity with the subject and the inaccuracies prevalent throughout the volume.

In a work of this kind, brief and concise statements are necessary in order to confine the volume to its proper size, but the different subjects should receive discussion more or less briefly according to their importance, and the more important subjects should not be neglected while the less important are treated in detail. The latter course not only prevents a book from containing as much useful information as it might otherwise do, but it also makes it extremely misleading to the student, for it gives him an erroneous idea of the relative importance of the different branches of the subject. Thus, in the present volume, the discussion of iron covers 27 pages. Of this number only 18 pages are given to the description of iron deposits proper, while nine pages are given to the enumeration of statistics which might have been condensed into a third of that space. Moreover, the great iron region of the Lake Superior country, which supplies more than two-thirds of the iron ore used in the United States, receives only three pages of treatment. The copper region of the Lake Superior country receives only four pages, and the copper and silver region of Butte City, Montana, one of the most celebrated mining localities in the world, receives only two pages; while other much less important subjects receive many pages. Such inequalities might be justifiable if the geology of certain regions were so simple that it could be described in a few words, even though the commercial features might be of great importance. In the instances cited, however, this is not the case.

Economic geology, including both the subject of ore deposits and other subjects which properly belong to this branch of geology, is in much need of accurate geological work and careful discussion. This is especially true in the United States, which is preëminently the mining region of the world; and it is unfortunate that a treatise relating mostly to the ore deposits of this country should have failed to give the subject thorough treatment. The volume, though in some parts it need not be severely criticised, shows in most parts an extremely superficial knowledge of economic geology, and contains many the errors in statements regarding the mineralogical nature of ores and geological nature of ore deposits; it shows a want of knowledge of the commercial features of the various mining industries, and it bears evidence of a lack of the sense of proportion in the amount of space given to different subjects.

R. A. F. Penrose, Jr.

The Canadian Ice Age. Notes on the Pleistocene Geology of Canada, with Especial Reference to the Life of the Period and its Climatal Conditions. By SIR J. WILLIAM DAWSON, G.M.G., LL.D., F.R.S., F.G.S., etc. Montreal: William V. Dawson, 1893. 301 pp., 8vo.

The work opens with a chapter of historical notices, embracing a sketch of the tenets held by the author during the long period of his studies on Pleistocene phenomena. Among these are the following: 1. The phenomena are not to be explained by any one cause, or by any one all-embracing hypothesis. 2. The astronomical changes that have been invoked are incapable of fully explaining the facts. 3. There has not been, at any time, a polar ice cap. 4. The phenomena indicate local mountain glaciers coöperating with floating ice in various forms. 5. The cold climate was mainly the result of peculiar geographical conditions and of a different distribution of oceanic currents. 6. The close of the period was not very remote. The author quotes freely from his previous writings in elucidation of these views, and cites certain recent tendencies that seem to him to indicate a drift of opinion towards the views he has held so long.

In the second chapter he gives the succession of Pleistocene deposits in Canada, as he correlates them, as follows:

Montreal and Lower St. Lawrence.	*North Shore of Lake Ontario.*	*Belly River, Northwest Territory.*
J. Wm. Dawson.	J. G. Hinde.	G. M. Dawson.
I.	I.	I.
Surface soil, post-glacial alluvia, and peat.	Surface soil, stratified sand and gravel.	Surface soil and prairie alluvium.
II.	II.	II.
Surface boulders, Saxicava sand and gravel. Boulders in and below sand.	Boulders, sand, etc. Laminated clay. Upper boulder deposit.	Upper boulder clay.
III.	III.	III.
Upper Leda clay, marine shells and drift plants. Lower Leda clay, marine shells and drift plants.	Stratified sand and clay, with fresh-water shells and plants.	Gray sand with iron-stone nodules. Brownish sandy clay. Carbonaceous layers and peat. Gray sand ironstone.
IV.	IV.	IV.
Lower boulder clay or till. Many native and some traveled boulders. A few marine shells of arctic soecies.	Lower boulder clay or till. Native and traveled boulders.	Lower boulder clay. Many traveled boulders.

This is followed by a general view of the entire series of deposits of eastern Canada and a discussion of these, in the course of which he states the views of the origin of the deposits which are set forth more fully in a subsequent part of the book. In the course of the chapter he presents a scheme of correlation of the phenomena of the glacial period in the Cordilleran region conjointly with those of the region of the great plains (in ascending order), in which epeirogenic movements constitute the leading feature. The following is an abbreviation :

Cordilleran Region.	*Region of the Great Plains.*
Cordilleran zone at a high elevation; severe glaciation; maximum development of Cordilleran glacier.	Correlative subsidence and submergence of the great plains with possible contemporaneous elevation of Laurentian axis and maximum development of the ice upon it.
Gradual subsidence of Cordilleran region; boulder clay of interior plateau and Yukon basin; lower boulder clay of coast region; interglacial silty beds at later stage.	Correlative elevation of western part of great plains, probably irregular; formation of extensive lakes; interglacial deposits, including peat beds.
Re-elevation of Cordilleran region; maximum of second glaciation.	Correlative subsidence of plains; submergence to base of Rocky Mountains; formation second boulder clay.
Partial subsidence Cordilleran region; formation of white silts; upper boulder clay of coast region, probably.	Correlative elevation of plains, probable formation of Missouri Coteau along shore line.
Renewed elevation of Cordilleran region; general amelioration, closing glacial period.	Simultaneous elevation of great plains to present levels; exclusion of the sea; formation of Lake Agassiz; gradation into present period.

Sir William Dawson would make three subdivisions of the Pleistocene period embracing (*a*) *Earlier Pleistocene;* irregular depression of the continents, with cold climate and great local glaciers; (*b*) *Middle Pleistocene;* submergence of coasts and re-elevation of interior plateaus, with milder climate—interglacial period; and (*c*) *Later Pleistocene;* submergence of plains and general ice drift with local glaciers in mountains. The succeeding thirty pages of the chapter are devoted to the description of the deposits.

The third chapter is devoted to physical and climatal conditions. In the course of this the author introduces a map to show the distribution of glaciated and unglaciated land, and of ice-laden and of ice-free

water during a typical stage of the Pleistocene period. Greenland, the Laurentian tract, the Adirondack, the northern Appalachian, and the northern Cordilleran regions are represented as glacial land. A broad tract sweeping around the Laurentian belt covering the Great Lake region and a large portion of the great plains of Canada is represented as submerged beneath an ice-laden sea. So also is a large area embracing Hudson's Bay and the adjacent straits. The Central American region is represented as extensively submerged and the equatorial waters of the Atlantic are represented as passing through to the Pacific.

Under the head of causes of glaciation, the author rejects with emphasis the prevalent glacial hypothesis, insisting strongly upon the impossibility of so great an ice sheet reaching to so low a latitude. He quotes extensively from Woeickoff in support of his position. The terminal moraines of most American writers he refers to deposition "at the margin of a sea laden with vast fields of floating ice," and thinks that some of the anomalies in their levels are due to differential elevation. He explains the striation (in regions not occupied by glaciers, under his view) by referring them largely to the action of "pan ice" aided by tides, especially on sinking coasts, and subordinately to iceberg action proper. His views on this point are well known. The very peculiar climatic conditions of the age are attributed to geographical changes, but the discussion is not carried into detail, and we have been unable to form a definite conception of the supposed method of causation.

The most valuable chapter, in our judgment, is that which relates to Pleistocene fossils. There is an admirable collection of data in detail, especially from the Lower St. Lawrence region—the richest of American fields in glacial paleontology. In regard to the relations of man to the glacial formations, Sir William Dawson apparently inclines to the interpretations of Professor Holmes.

At the close of the work complimentary reference is made to Howorth's book, "The Glacial Nightmare," and the similarity of views there expressed to those of the present work approvingly noted. Tactically we think this is an error, since conclusions associated with field experience such as those of Dr. Dawson will be likely to be placed by geologists in quite a different category from the dialectic lucubrations of a mere academic treatment. Support must be scant when "The Glacial Nightmare" is counted in.

The present writer dissents radically from the author's fundamental conclusions and from his estimate of the present drift of opinion, but finds the book interesting and suggestive, and its contributions to Pleistocene paleontology notably valuable. T. C. CHAMBERLIN.

The Post-Pliocene Diastrophism of the Coast of Southern California. By ANDREW C. LAWSON. Bulletin of the Department of Geology, University of California Vol. 1, No. 4, pp. 115–160, plates 8–9.

IN this bulletin, Professor Lawson presents the results of some of his studies on the west coast of California. The essay concerns itself especially 1° with the coasts of San Diego and Los Angeles counties, and with the islands of San Clemente and Santa Catalina which lie a few miles to the west; and 2° with the coastal region from Santa Cruz to the Golden Gate. So far as concerns the southern region, the data are drawn principally from four localities. These are: a) the coastal slope of San Diego county,—the San Diego mesa; b) San Pedro Hill; c) San Clemente Island; d) Santa Catalina Island.

The San Diego mesa is a terraced plain having a breadth of from twelve to eighteen miles. It is characterized as a Pliocene delta, made up principally of Pliocene sands and sandstones, but covered by a thin sheet of river gravels. The evidence for the statement that these gravels are of fluviatile origin is not given. The gravels are thought to have been deposited approximately at sea level. They now stand at a maximum elevation of nearly eight hundred feet. The inference is that an elevation of eight hundred feet has taken place along the coast of San Diego county since Pliocene time. Various marine terraces at levels of seven hundred feet and less characterize the mesa.

San Pedro Hill is an abrupt headland on the coast of Los Angeles county. Its slopes likewise show a series of marine terraces and sea-cliffs. The highest terrace on this headland stands at an elevation of 1240 feet. There are many lower terraces on the San Pedro Hill, the lowest mentioned having an altitude of 120 feet. Through the higher terraces the streams have cut for themselves cañons; but they flow over the lower terraces in shallow channels. This is evidence of the recency of the elevation marked by the lower terraces. Molluscan borings in the old sea-cliffs, up to an elevation of 1240 feet, may still be seen.

From the relations of the Miocene to the Pliocene formations of the headland, it is inferred there was an "important interval of denu-

dation between the Miocene uplift and the depression which permitted the deposition on the lower flanks of the hill of the formations which paleontologists recognize as of Pliocene age. The recovery from this Pliocene depression is the uplift which is registered in the elevated strands of the hill." The uplift following the Pliocene depression is regarded as Pleistocene. This conclusion is of course warranted, if the Pliocene strata involved are known to belong to the closing stages of the Pliocene period. Otherwise it does not appear that the conclusion is a necessary one. Pleistocene strata are referred to as overlying the Pliocene, and as belonging to a recent stage of the uplift. Between the Pliocene and the Pleistocene no evidence of subaërial denudation exists.

On the west side of San Clemente Island seventeen well marked terraces occur, the highest at an elevation of 1320 feet. These terraces are from 200 to 1500 feet in width. There are less distinct terraces up to a height of 1500 feet. "The total amount of horizontal sawing which has been effected on the slopes of the island by wave action during its elevation through the last 1320 feet," is more than two miles.

Santa Catalina Island is of about the same size, trend, and height as San Clemente. It has a position midway between San Pedro Hill and San Clemente; but on Santa Catalina "there is no trace of an elevated wave-cut terrace, sea-cliff, or strand line of any kind observable." Furthermore, "The stream topography of the island is very much more advanced, *i. e.*, much more ancient than that of either San Pedro Hill or San Clemente."

The absence of terraces and sea-cliffs cannot be attributed to the character of the rock, and their absence is in harmony with the condition of the stream valleys, which indicate that the island has not been below the sea in recent times; that is, "Santa Catalina has not been subjected to the uplift which has affected the two prominent insular masses, one twenty-five miles to the north of it, and the other twenty-five miles to the south of it." Not only has Santa Catalina not been elevated while San Pedro and San Clemente were undergoing the great uplifts which have been mentioned, but it is believed to have actually sunk while these other land masses were being lifted. The evidence of sinking is found in the drowned valleys of certain parts of the coast, and in the falls and rapids which mark the termini of the streams of other parts. Santa Catalina would appear to be situated in

the trough of a syncline which has been actually sinking while the lands on either side were rising.

The coast of the Bay of Monterey is also marked by a series of terraces. Four of them, the highest of which reaches an elevation of 712 feet, are very distinct, and abut against sea-cliffs. Higher terraces extend up to an elevation of 1201 feet. The river valleys also of the Santa Cruz region are found to afford evidence in harmony with that already cited from the regions further south. The general tenor of the evidence presented by this part of the coast is therefore in harmony with that presented by the more southerly region. Here also there has been a marked epeirogenic movement in recent times.

On the peninsula of San Francisco, marine Pliocene rocks, having a thickness of more than one mile, are said to exist. It is believed that subsidence accompanied the accumulation of this great series. These strata now occur at an elevation of over 700 feet. Not only this, but the strata have been so tilted, and subsequent erosion has been so great, that the base of the series, as well as the top, is exposed at this elevation. The elevation is said to have been post-Pliocene. Of course this is true, if the uppermost Pliocene strata involved represent the close of the Pliocene period.

According to the author, the relations of the Pliocene strata indicate great orogenic as well as epeirogenic movements in this region since their deposition. Montara Mountain is believed to have been produced during the orogenic event by which the Pliocene rocks (Merced series) were lifted into their present position. The granite axis of the mountain is regarded as the up-thrust base on which the Pliocene strata were laid down. All the adjacent younger strata dip away from this granite axis quaquaversally. While, therefore, the general structure of the mountain is comparable to that of a laccolite, it is, according to Professor Lawson, very different from it genetically.

On the basis of the facts given in the paper, there would appear to be no ground for doubt concerning the main conclusions at which Professor Lawson arrives concerning the movements of the coast in recent times. On the basis of evidence presented, there might be some question as to the post-Pliocene date of all these changes of level, did not Professor Lawson define the Pleistocene so as to include them. He says (p. 159), "It is not an easy matter to delimit the Pliocene and Pleistocene epochs so that they shall correspond to the same divisions of the geological scale in the eastern part of the continent. . . . . The rea-

son for this is that there has been no distinct break in the continuity of marine conditions throughout the epochs, only a gradual transition of conditions. In this gradual transition there was, however, a reversal of the epeirogenic movement of the coast from a process of depression to a process of uplift. This turning point of the disastrophic pendulum . . . . is believed to correspond well with the beginning of the Pleistocene." With this definition of the Pleistocene, of which we are not disposed to complain, there can be no doubt as to the age of the remarkable changes of level which Professor Lawson describes. It is to be hoped that at some future day he may give us an account of the corresponding phenomena along a greater and connected stretch of the California coast. The results announced in this paper purport to be no more than the results of a general reconnaissance of the regions described.

ROLLIN D. SALISBURY.

Analytical Abstracts of Current Literature.

Ein typisches Fjordthal. von Erich von Drygalski. z. Z. GRÖNLAND. 14 pp.

Dr. Drygalski describes in detail a valley on the west coast of Greenland, one peculiarity of which is that there are three considerable depressions along its axis. These are occupied by lakes, some of which certainly, and all of which probably, have rock basins. Another peculiarity of the valley is that it crosses a narrow highland between two fjords. One end lies at the sea level, the other 211 m. above it, the slight drainage through the valley having a fall of this amount at the end of the valley. This latter point is nearly 100 m. below the divide in the valley, from which drainage flows in opposite directions. The valley is about 5½ km. long, about 1 km. wide, and has an average depth of about 336 m. While the valley is well above sea level, and therefore no fjord, it is pointed out that, with a relatively higher sea, it would become a fairly typical fjord. In the judgment of the author, the situation is such as to preclude the idea that the valley is a river valley, or that it is a river valley modified by ice action, and the author is "very much inclined to extend this conclusion to the fjords" he has seen. Dr. Drygalski advocates the view that this valley owes its origin primarily to the weathering of the gneiss in which it lies, and suggests that joint-planes, by determining the position of greatest weathering, determined also the position of the valley. Subsequently, after the valley had come into existence by weathering, the ice removed the weathered products, and an undetermined depth of solid rock below. The author leaves it to be understood that this is, in his judgment, a principal, if not the principal method by which the fjords with which he is familiar have originated.

R. D. S.

A Preliminary Report on the Cretaceous and Tertiary Formations of New Jersey. By WILLIAM BULLOCK CLARK, Annual Report of the State Geologist of New Jersey, 1892.

This report presents the results of investigation conducted by Professor Clark and his assistants during the year 1892 upon the coastal plain formations of New Jersey. The report, with a new geological map, covers the area of the U. S. Geological Survey atlas sheets of New Brunswick and Sandy

Hook. The text contains an historical sketch in which the work of past investigators is briefly cited, and reference made to the various views upon the classification and correlation of the several formations. A second chapter is devoted to a consideration of the physical features of the coastal plain, following which is an extended statement in regard to the stratigraphical characteristics of the formations found there. Although an attempt is made to make the classification of the deposits coincide, so far as it is possible, with the investigations of the late Professor Cook, yet some changes of importance are considered to be necessary. The name Raritan formation is proposed in place of the wholly inadequate term Plastic Clay, and the Upper Marl bed, which is in part Cretaceous and in part Eocene, is divided into Manasquan Marl and Shark River Marl respectively. The division of Yellow Sand proposed by Professor Cook is not held to be an independent formation, but is included under the Manasquan Marl. The Miocene is considered to be extensively developed in New Jersey. Although fossils have been found at only a few points, they are thought to be sufficient in number to indicate a series of deposits several hundred feet in thickness and many square miles in surface exposure.

In summing up his statements in regard to the relation of the several formations, Professor Clark says, "the deposits of the coastal series of New Jersey show complete conformity from the bottom of the Raritan formation to the top of the Upper Marl bed, while no wide-reaching dislocations of the strata have been observed at any point. The strike follows a nearly continuous trend of N. 50 E., while the dip is twenty-five to thirty feet in the mile to the southeast. Overlying the Upper Marl bed unconformably is the Miocene, which possesses the same general structural and stratigraphical features as the earlier members of the series."

The origin of greensand, which characterizes so many of the coastal plain formations of New Jersey, is fully considered, the results by Professors Murray and Renard, of the Challenger Expedition, being given with much fullness. The geological distribution of greensand is briefly reviewed, and the character of the New Jersey deposits more fully considered. Three colored plates are reproduced from the Challenger Expedition report on Deep-Sea Deposits, to illustrate the mode of formation of glauconite. R. D. S.

The Pleistocene Rock Gorges of Northwestern Illinois. By OSCAR H. HERSHEY. American Geologist, November, 1893.

The object of this paper is to ascertain the length of the "deglaciation interval and perhaps interglacial epoch." The ice of the maximum period of glaciation affected this region but slightly. In some cases the glacial sand and gravels were deposited in ridges transverse to the streams' courses, thus damming the streams and producing small lakes. Sometimes the barriers were so

high that the course of drainage was altered. The new valleys were cut in Galena limestone. The amount of cutting in the limestone since maximum glaciation is about equal to that in the newer drift in the vicinity of Lake Michigan. The later work has been going on, it is believed, about 7000 years. It is estimated that erosion in the limestone of northwestern Illinois took place one tenth as fast as in the drift. On this basis 70,000 years have been required for the erosion accomplished in northwestern Illinois since the maximum period of glaciation. Long after the withdrawal of the maximum ice-sheet, a mantle of loess was spread over northwestern Illinois. The writer thinks that something like four fifths of the erosion accomplished since the withdrawal of the maximum ice-sheet was accomplished before the deposition of the loess. Fifty thousand years are considered a minimum, and perhaps twice that time not too great an allowance of time, for the erosion that took place between the time of the formation of the drift sheet in northwestern Illinois and the deposition of the loess. J. A. B.

Notes on the Sea-Dikes of the Netherlands. By PROF. J. C. SMOCK. (Annual Report of the State Geologist of New Jersey, 1892, pp. 315–329).

These notes are descriptive of the dikes at the Helder and at Petten in North Holland, and at West Kappele in Zealand. The breaks in the coastal dune ranges are occupied by them. The whole sea-front is protected by a system of jetties also. They are built on the strand and in front of the dikes—and check the currents which carry away the beach sands and tend to undermine the dune hills at these localities. The dikes are essentially enormously thick walls of sand whose outer slope is at a low angle, and is faced with stone and further protected by rip-rap and by piling. The descriptive notes of the construction are illustrated with plans and vertical cross-sections.

The application of a modified system of sea-dikes for the protection of the bluffs at Long Branch, New Jersey, follows. The reclamation of the tidal lands of the state is referred to, and the reclamation of the low-lands of Holland affords an instructive example.

J. C. S.

THE

JOURNAL OF GEOLOGY

APRIL-MAY, 1894.

THE OIL SHALES OF THE SCOTTISH CARBONIFEROUS SYSTEM.

The Lower Carboniferous Rocks of the east of Scotland have within the last quarter of a century attained great economic and geological interest from the oil-bearing shales they have been found to contain. The district around Edinburgh is one of great complication, and until the operations of the shale mines began large parts of the ground which is usually deeply covered with glacial drift were geologically but imperfectly explored. It is only recently that the chief oil shale districts have been mapped correctly, and the new edition of the geological map of the Edinburgh district, on which I have been engaged for several years tracing out the oil shale outcrops, etc., has only been published within the last six months. A detailed account of the structure of this area has not yet been published, and beyond a few short papers by myself and others in various scientific journals, nothing of importance has been written on this interesting subject.

The Carboniferous system of Scotland is broadly divisible into the following groups:

4. *Coal Measures, with the most important coals.*
3. *Millstone grit, chiefly barren sandstones.*
2. *Carboniferous Limestone Series, with beds of limestone above and below, and shales, sandstones, etc., interbedded with seams of excellent coal in the center.*
1. *Calciferous Sandstone Series, with sandstones, estuarine limestones, marls, seams of oil shale and occasional impure coal, the*

base of the series consisting of coarse red sandstones, shales and marls resting on the Old Red Sandstone.

The oil shales of Scotland are confined almost exclusively to the "Calciferous sandstone" strata in the Edinburgh district, and the principal seams occur in West Lothian, where the most important oil works are situated, about twelve miles west of the Scottish metropolis.

Broadly speaking, Edinburgh is situated on a great anticline, in the center of which there rises a ridge of Silurian and Old Red Sandstone rocks, partly igneous and partly sedimentary, whose general strike is northeast and southwest. The hard volcanic strata and igneous intrusions in these older rocks have produced most of the pictureque ranges of hills in the vicinity of Edinburgh, and the softer beds in the higher parts of the series dip away, with many complications, from either side of the central axis. To the east of the Pentland ridge the inclination of the beds is very high, and comparatively regular, and consequently the whole thickness of the calciferous sandstone series can be traversed in a short time. There is also here a large fault running along the base of the hills which conceals the lowest of the calciferous series of rocks and brings up the old volcanic beds against the upper parts of the oil-bearing strata, and indeed at one place the dislocation has been so great that the calciferous rocks with their oil shales are almost entirely hidden, and the upper beds of the Old Red Sandstone abut almost directly on the base of the marine limestone series.

The Carboniferous limestones along this line, with their interbedded coal seams, are inclined for long distances at the same high angle and plunge at places almost vertically downwards beneath the long and regular trough of Dalkeith Coal Measures, from which they emerge five or six miles farther east at a much lower inclination.

To the west of the Edinburgh anticlinal the structure of the district is much more complicated. The Calciferous rocks spread out for fifteen or sixteen miles in a tumultuous sea of undulations, basins and folds cut up by multitudes of faults, and

traversed by numerous necks, sheets and dykes of intrusive igneous rock, to map which, even with the aid of copious mining information, is often a task of the greatest difficulty. The rapid thinning and thickening of some of the members of the series also adds an element of difficulty to the elucidation of the structure of the district, and although many hundreds and even thousands of borings have been made in search of oil shale and other rocks, there are places where, in the absence of surface exposures, the structure of the area has still to be ascertained.

The total thickness of the Carboniferous Limestone series of Mid and West Lothian is about 2,000 feet, and that of the upper or oil shale division of the underlying calciferous series is a little over 3,000 feet. Beneath the oil shale series there is a group of shales, fire clays and gray sandstones, one of which, formerly quarried very extensively at Craigleith, supplied nearly all the celebrated freestone from which a large part of the New Town of Edinburgh was built. Owing to its great hardness and cost of working the Craigleith stone has now been nearly given up and is only used where great strength is wanted in house architecture, or for export to America, where it appears to be used occasionally for special work. This middle division of the Calciferous Sandstone series appears to be about 3,000 feet thick, and the red beds which lie below cannot be much thinner, so that 9,000 feet may be taken as the approximate distance from the top of the Old Red Sandstone to the highest part of the Oil shale series in this locality.

Dealing now in greater detail with the Oil shale group of rocks, it may be noted, first, that the whole series has a fresh water or estuarine character, and contains few or no strata of a marine type. There are numerous thin bands of concretionary unfossiliferous limestone, and one well-marked bed of richly fossiliferous estuarine limestone of workable thickness. This rock—the Burdiehouse Limestone—in addition to fresh water shells, contains fish plates, teeth, etc., and many plant remains such as *lepidodendron* and *sphenopteris*, and is at places directly

covered by a bed of black bituminous shale of inferior oil-producing quality. The series is also characterized by numerous well-marked beds of unfossilferous red, green and gray marl, the origin of which is not very clear, but as the marl is seen at places to contain pieces of felspathic volcanic ash, it seems reasonable to suppose that it may be made up in part at least of impalpable mud derived either from volcanic dust or from the disintegration of some old volcanic area which has now disappeared from view, but which formed part of the ancient mainland from which the other sediments were derived. There is no distinct evidence of volcanic action during the greater part of the Oil shale period in the Lothians, and the numerous ash necks which pierce the strata were probably connected with the extensive outbursts which took place during the subsequent Carboniferous Limestone period. Many beds of gray and yellow sandstone are found interbedded with the oil shales as well as impure coals, fire clays, and non-bituminous carbonaceous shales —the "blaes" of the Scottish mines, in which plant remains, and fresh-water molluscan forms are at places found in abundance.

The Scottish Oil shales are simply beds of very fine impalpable clay shale highly impregnated with hydrocarbon, easily distinguished in the field by their resistance to the disintegrating action of the weather, thin brown streak, and the facility with which they can be cut and curled up with a sharp knife. The texture is at times tough, almost leathery, and thin pieces are slightly flexible and easily distinguishable from ordinary black carbonaceous "blaes" with which they are often closely associated. When lit with a match oil shale burns, as a rule, brightly, leaving a finely laminated skeleton of ash after all the hydrocarbon has been exhausted. On distillation the yield of oil varies. Good shales should give, per ton, at least thirty gallons of crude petroleum, as well as enough ammonia to produce, when neutralized with sulphuric acid, from ten to fifty pounds of sulphate of ammonia. This product is often as valuable as the oil, and much skill has been employed in the construction of retorts to extract it completely. The crude oil when refined gives various

products, such as tar, naphtha, paraffin, light illuminating and heavy lubricating oils, and the oil industry of the Lothians was for more than a quarter of a century a source of great profit and employment to the capitalists and operatives of the district, but of late years the severe competition with foreign producers has made most of the works quite unremunerative. The thickness of the oil shale beds varies considerably from place to place, and it is quite common to find a good seam thinning out in one district and passing into ordinary carbonaceous shale, or disappearing altogether, while another seam above or below it may improve in quality in proportion as the first deteriorates. The Broxburn shale—the richest seam in the Broxburn district—varies in thickness from about two and a half to eight feet, and the Dunnet shale reaches at places a workable thickness of thirteen feet.

An interesting phenomenon is observable at some places where the strata have been heated by igneous intrusions. In these cases if an oil shale bed has been affected by the heat, partial distillation has followed, and the surrounding rocks, including the eruptive sheet itself, have become impregnated with the hydrocarbonaceous ingredients expelled from the shales. In a recent diamond boring a core of the eruptive dolerite was brought up from a depth of over 600 feet, traversed by veins of solid paraffin, which melted when the rock was laid in the sun, and at the outcrop of this intrusive sheet it is found to contain cavities filled with tarry matter and to give off a strong bituminous odor when freshly broken with the hammer. This eruptive sheet has forced its way for miles through strata adjoining the Broxburn shale, and whenever it has touched or even approached the shale the seam has of course become quite worthless economically. The well-known sandstone of Binney, which is located some fathoms below the Broxburn shale, has long been known to contain veins of ozocerite or an allied hydrocarbon, and the quarrymen used formerly, when the rock was extensively worked for building and monumental purposes, to make black candles of the substance, some

of which are still preserved in the Science and Art Museum in Edinburgh. There can be little doubt that this "mineral" owes its origin to the distillation of the bituminous matters by the igneous intrusions in the vicinity of the overlying oil shale.

The oil shales occur within an area roughly twenty miles in diameter. On the north shore of the Firth of Forth only one seam of workable quality is known, and all the others have apparently disappeared and become replaced by more arenaceous rocks, while in the Lower Carboniferous deposits in other parts of Scotland no oil shales of any value have been yet discovered. These valuable deposits appear to have been found in broad lagoons into which vegetable matter was brought in a very fine state of division, and laid down along with a small quantity of inorganic silt under conditions of great tranquillity. That the hydrocarbon is however sometimes of animal origin is clear from the quantity of cyprids that make up some of the shales. Large plant remains are rare, but beautifully preserved fronds of *sphenopteris affinis*, and other ferns are abundant in some of the beds of oil shale. There cannot have been currents of any strength sweeping through the lakes of the Scottish oil-shale period, otherwise the light organic particles would have been at once swept away, and this order of things must, with periodical interruptions, have obtained within the shale region for a long succession of ages, during which deposits accumulated to a depth of over 3,000 feet.

Liquid petroleum has been occasionally found exuding in small quantities from the joints of these sedimentary rocks, and there is at St. Catherines, about three miles south of Edinburgh, a spring situated on the line of the great fault east of the Pentland axis already referred to, known for many centuries as the Balm Well, whose surface is covered by a film of mineral oil derived no doubt from the slow distillation of the oil shales on the downthrow side of the dislocation. We cannot, however, boast of anything like the famous oil wells of Pennsylvania, which I had the pleasure of visiting in 1891, and even were there rich oil sands among the Califerious sandstones of the

Scottish Lothians, the exceeding faulted and disturbed nature of the Carboniferous system in this locality would effectually prevent the circulation underground of any quantity of fluid hydrocarbons except within extremely limited areas.

The following is a general section of the oil shale series west of Edinburgh:

	FEET.
Strata below base of Carboniferous Limestone series about	400
Raeburns Shale, 3 to 4 feet strata, - - - -	190
Mungals Shale, about 1 ft. 9 ins. strata, - - -	170
Coal and Gray cypride Shale 2 ft. "Houston Marl" group	200
Strata laminated sandstones, - - - - -	240
Fells Shale, 3 to 5 feet, "Broxburn Marl" group, 80 to	270
Broxburn Shale 2½ to 8 feet, "Binney Sandstones" and strata, - - - - - - - -	450
Dunnet Shale, 6 to 13feet, strata chiefly shales, fire clays, etc.	400
Barracks Shale, resting on the estuarine Burdiehouse Limestone, 10 to 50 feet thick at places, strata about -	780
Pumpherston Shales, about 6 feet worked.	
Apparent thickness of Oil shale series, - - -	3,100

HENRY M. CADELL.

THE CRETACEOUS RIM OF THE BLACK HILLS.[1]

As is well known, the Black Hills District was surveyed by the party in charge of Professor W. P. Jenney in 1875, the geological report being written by Professor Henry Newton, whose death occurred two years later. The report, edited by Mr. G. K. Gilbert, was published in 1880 by the U. S. Geographical and Geological Survey of the Rocky Mountain Region in charge of Major J. W. Powell. The peculiar and interesting geological features of this remarkable outlier of the Rocky Mountain range need not be set forth here further than to say, that on all sides after leaving the central nucleus of eruptive rocks sedimentary deposits occur with diminishing dip in an ascending geological order. First, there is a narrow ring of Potsdam sandstone; then a wide belt of Carboniferous limestone; next an encircling trough, aptly compared by Professor Newton to a moat, of red sandy gypsiferous clays, in which is included a purple limestone terrace, all of which is supposed to be Triassic and to be the equivalent of the "Red Beds" of more southern regions; skirting this is a very narrow border of highly fossiliferous light colored Jurassic clays or marls; then come the foot-hills, which consist of Cretaceous sandstones and shales referred by Professor Newton to the Dakota, No. 1, of Meek and Hayden's section; these slope back to the dark shales of the Fort Benton group, which are succeeded by higher Cretaceous beds that extend to the plains and pass under the Bad Lands of the White River formation.

The belt of Cretaceous, which lies outside the Red Beds and Jurassic and forms the foot-hills, constitutes an elevated rim with an escarpment at its inner margin rising abruptly above the Triassic trough, the Jurassic exposures being often confined to the lower part of the escarpment. This cannot be better rep-

[1] Published with the permission of the Director of the U. S. Geological Survey.

resented than in the following figure copied from Professor Newton's report:[1]

At that date the opinion widely prevailed that there was no Lower Cretaceous in North America. The Shasta, Kootanie, and Comanche groups were unknown, the Potomac of Virginia was supposed to be "Upper Oolite," and the Iron Ore Clays of Maryland and Plastic Clays of New Jersey were classed as Wealden and referred to the Jurassic. Meek and Hayden had been unable to find any Cretaceous deposits lower than No. 1 of

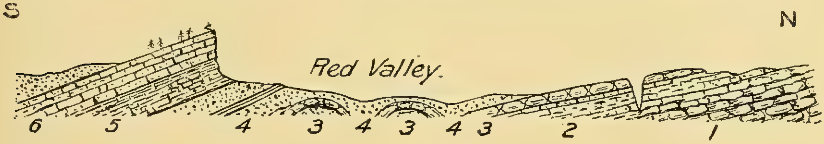


FIG. 1.—Ideal section across Red Valley on Amphibious Creek.

1. Carboniferous.
2. Red sandstones and clay (Red Beds).
3. Purple limestone (Red Beds).
4. Red clay with gypsum (Red Beds).
5. Jura.
6. Cretaceous sandstone capping the foot-hills.

their famous section, and this was believed to be the oldest Cretaceous deposited on this continent, which was supposed in some way to have been out of water during the entire period that separated this from the Jurassic.

My attention was first attracted to the Black Hills by a letter received at the Smithsonian Institution in February, 1893, from a resident of Hot Springs, South Dakota, inclosing photographs of certain petrifactions found in that vicinity which he said had been called "Cycads." The letter and photographs were referred to me on the presumption that these objects were of vegetable origin. I at once perceived that they were fossil cycadean trunks closely resembling those collected by Tyson in 1860 in the Iron Ore Clays of Maryland and named by Professor Fontaine *Tysonia Marylandica*, and, therefore, also similar to the forms found by Mantell and others in the early part of the cen-

[1] Geol. Black Hills of Dakota, p. 141, fig. 20.

tury in the Purbeck beds on the Isle of Portland and at other points in the South of England. Being greatly interested in the discovery, I recommended that the proprietor be requested to send on a specimen for examination. The request was complied with, and the specimen proved to be all that I had expected. I therefore made the further recommendation that negotiations be entered into with a view to the purchase of the collection of six specimens which were offered for sale. This was also successful and the collection arrived in May.[1] One of the chief features of these specimens is the great size of some of them, the largest measuring 30 inches in height, 2 feet in its longest diameter, and weighing 900 pounds, thus far exceeding anything of the kind hitherto known from any other part of the world.

Fossil remains of cycadean trunks range from the Upper Trias to the Lower Cretaceous. A number have been found in the clay shales of Italy which have been referred to the Cenomanian, but will probably be found to be lower. Hot Springs is located on the Red Beds in the valley of the Minnekahta creek, or Fall River, and it would have been natural to suppose that the cycad trunks had come either from these or from the Jurassic which borders it, had it not been stated that they were found "on a high hill." My interest was of course strongly aroused to know the stratigraphical position of the beds in which they occurred, and therefore early in September I made an expedition to the region for the purpose of determining it if possible. I had previously corresponded with Mr. F. H. Cole, of Hot Springs, from whom the specimens had been purchased. I had also written to Professor Jenney, who was then at Deadwood, and who kindly consented to join me on my arrival and aid me in the investigation. After considerable search and some difficulty the locality was at length found. It is some four miles southwest of Minnekahta Station, about two miles west of Minnekahta Creek, which here has a northward course, on foothills one and a half miles east of the divide between that and Red Valley. A deep cañon lies to the south, which has an east

[1] See Science, Vol. XXI., No. 543, June 30, 1893, p. 355.

course and opens into the Minnekahta Valley. The locality is on the southeast slope, just below the top of the flat-topped spur-ridge and near the abrupt descent into the cañon. From this point northwest to near the crest of the divide the slope is moderate and nearly uniform.

The accompanying sketch-map (Fig. 2) showing the drainage of the region north of the south fork of the Cheyenne river, the Minnekahta Valley, and part of the Red Valley, will enable the reader to understand the general character of the country covered by this reconnaissance.

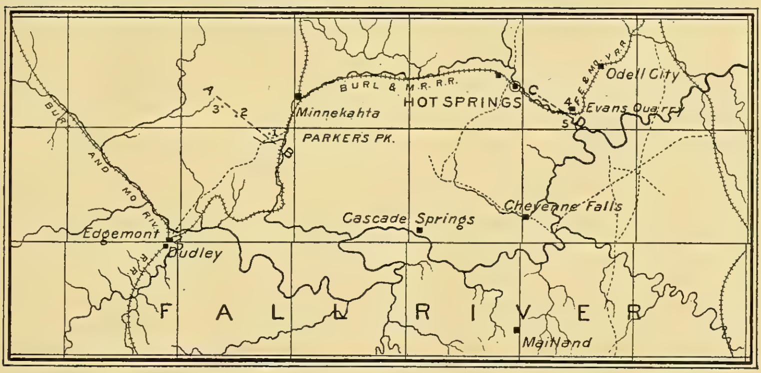


FIG. 2.—Sketch-map of a portion of Fall River County, South Dakota.

A B. Section No. I.
1. Cycad bed.
2. Fossil forest.
3. Plant bed.

C D. Section No. II.
4. Upper leaf bed.
5. Lower leaf bed.

At the foot of this crest on the same (southeast) side, and about one and a half miles northwest of the cycad locality, occurs an extensive fossil forest. The wood is all completely silicified, and consists of prostrate trunks of various sizes and lengths and an abundance of smaller fragments, many of which are scattered about on the sloping plain a long distance below the actual horizon at which they were petrified. At that horizon many still remained apparently undisturbed, and in one place a trunk eight inches in diameter was seen projecting several feet from beneath the massive sandstone ledge. To the south of this point is a

saddle, beyond which the crest of the divide is lower, and here the forest is seen to the best advantage. The most prominent object is an immense trunk, thirty inches in diameter and twenty feet long, lying where it fell at no very remote date, having broken from its roots at the surface of the ground, leaving portions of the stump still exposed. The entire root could probably be exhumed. About the present trunk the lines of splinters and smaller fragments clearly indicate the character of its branches and show that these branches remained attached at the time it fell. A considerable amount of silicified wood occurs also at the same locality as the cycads, obviously preserved by the same influences that preserved the latter. The slope from the fossil forest to the cycad bed is about the same as the dip of the strata. It is therefore probable that both occur approximately at the same horizon. The whole of this region, including the entire crest of the divide and extending to the bottom of the cañon below the cycad bed and far to the southeast, consists of the series of sandstones that have been treated in the Black Hills report as the "Dakota Group."

The great improbability that the cycads could have lived in the Dakota period, or Upper Cretaceous, led us to undertake an investigation of these rocks with a view to the possible discovery of additional evidence of their age. No other fossil remains than the wood and cycad trunks could be found in the immediate vicinity or anywhere on the outer slope of the Cretaceous rim. The crest above the fossil forest consists of harder sandstones, chiefly massive, which may be traced far around the Hills, and which form the upper part of the abrupt escarpment above the soft Jurassic and Red Beds. Passing over this to the northwest we descended into the first lateral cañon entering Red Valley from the northeast. The Jurassic is passed through and the Red Beds fairly entered in the descent. Fifty to seventy-five feet above the Jurassic contact and 175 to 200 feet below the summit of the crest, argillaceous shales with some carbonaceous matter occur interstratified with the sandstones, and at this level, partly in the shales and partly in the rocks, a few fos-

sil plants were found and a small collection made. They bore no resemblance whatever to the flora of the Dakota Group, but consisted chiefly of ferns with a few coniferous twigs and possibly cycadean remains. In short the flora, so far as I could judge, was rather that of the Lower Cretaceous.

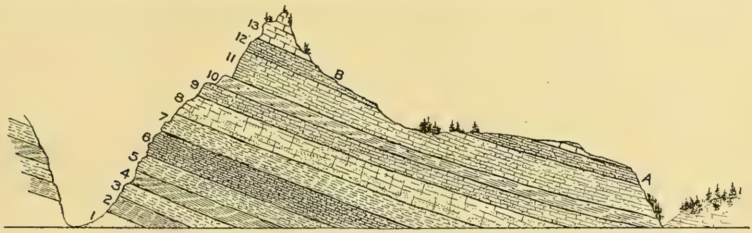


FIG. 3.—Section across the divide between Red Valley and Minnekahta Creek.

1. Red Beds.
2–7. Jurassic.
9. Plant Bed.
12. A, Cycad Bed. B, Fossil Forest.
13. Equivalent of Quarry Sandstone in Section No. II.

The entire section, from the Red Beds at the bottom of the cañon to the summit of the crest forming the divide, was carefully measured, the position of the fossil forest bed, the cycad bed, and the plant bed, fixed as nearly as the circumstances would permit, and all the variations in the nature of the strata indicated. The section, as determined on the spot, is as follows:

SECTION NO. I.

Dakota of Newton. 275 Feet.

13. Massive pinkish sandstone approaching a quartzite locally	75 feet
12. Grayish white sandstone with silicified wood and cycads	30 feet
11. Pinkish and yellowish soft sandstone	75 feet
10. Clays with indications of coal	20 feet
9. Soft pink and gray sandstone with ferns and other plants	25 feet
8. Reddish, pinkish, and yellowish-brown massive cross-bedded sandstone	50 feet

Jurassic. 220 Feet.

7. Olive gray clay and sandstone shales	50 feet
6. Light red soft sandstone	60 feet
5. Olive gray clays and gray sandstone shales	40 feet
4. Olive drab clay	20 feet
3. Yellow sandstone shales	20 feet
2. Olive drab clay	30 feet

Red Beds (Trias).

1. Red marls, conformably exposed at bottom of cañon	20 feet

This section may be represented diagrammatically in Fig. 3.

The Minnekahta Creek, or this southern fork of it, after flowing north through the Cretaceous, enters the Red Beds a little south of the Minnekahta Station, after which it bends to the eastward and follows the strike to Hot Springs. Below this point it takes a southeasterly course, and soon reënters the Cretaceous, cutting entirely through the sandstone and entering the dark Fort Benton Clays a short distance below the cataract at the electric light plant nearly five miles from Hot Springs at Evans Siding. Evans Quarry is just above this point on the left bank. At the last named place Professor Jenney had formerly obtained dicotyledonous leaves, and it was his impression that these might have come from near the horizon of the cycad bed. This region presents an admirable opportunity for measuring a section of the Cretaceous, which it was very desirable to do for comparison with the one last given.

The distance at the bottom of the valley from the Jurassic contact to the Fort Benton is about three miles, and the dip, as the section shows, is over 100 feet to the mile. The quarry is about one-half mile from the point where the sandstones pass under the Fort Benton shales. It has a thickness in workable stone of about 60 feet, and is immediately capped by 40 or 50 feet of softer material. It dips very rapidly to the southeast so as to come down to the stream at the electric light plant, and constitute the rock over which the cataract flows and through which the water has here worn deep longitudinal grooves. Immediately over these rocks and resting upon them there is a bed some six or eight feet in thickness of dark clay and argillaceous shales with carbonaceous matter and some impure coal. In this bed was found a great abundance of more or less comminuted vegetable matter, with short fragments of culms or reed-like plants not determinable. There also occurred in certain of the shales a few tolerably well preserved dicotyledonous leaves, some of which are determinable. They were at least sufficient to indicate with practical certainty that this stratum belongs to the Dakota Group of Meek and Hayden (No. 1). A small collection was made at this point, viz., at the cataract

over the hard sandstones on the right bank of the stream above the electric light plant (5, Fig. 2).

This bed was easily followed to the quarry, where it constitutes the overlying mass which it is necessary to remove in order to uncover the workable sandstone below. At this point the bed also contains layers of soft white sandstone more or less massive. Large blocks of this had been thrown down and lay strewn at the foot of the quarry. On the surfaces of these and more or less scattered through their mass were impressions of dicotyledonous leaves of Dakota types. The shales were also found in places above the quarry, and some of these yielded very good specimens (4, Fig. 2).

The massive sandstone of the quarry is entirely barren so far as could be ascertained, and no fossils were found at any point lower than the bed that overlies it. For a long distance on both sides of the cañon it forms the crest of the ridge, presenting a more or less abrupt escarpment of from 25 to 75 feet. Below it, higher up the stream, beds of softer sandstone, argillaceous shales, and carbonaceous layers with impure coal seams, all highly charged with gypsum, come down to the bed of the stream, and are finally seen resting upon the Jurassic clays, which in turn overlie the Red Beds. Some distance below Hot Springs the Cretaceous can be seen at the summit of the cliffs, with the whole thickness of the Jurassic below them and the Red Beds at the base. At and about Hot Springs there are some heavy beds of conglomerate about which little seems to be known.

The following is the Cretaceous section as measured:

SECTION NO. II.

Fort Benton.

11. Grayish black clays with layers of ferruginous concretions, extending to the south Fork of the Cheyenne River—contact conformable.

Dakota of Newton. 339 Feet.

10. Pink sandstone, mostly thin-bedded, with ripple-marks and fucoid-like impressions .... 30 feet
9. Soft black shales with traces of carbonized plant remains and some fragments of fossil wood .... 15 feet
8. Pink and gray sandstone .... 30 feet

7. Clay shales and sandstones, the latter sometimes white, all plant bearing, much comminuted vegetable matter, matted beds of swamp plants, and well-preserved dicotyledonous leaves of Dakota types, determinable... 10 feet
6. Black clay full of carbonaceous matter, with locally six inches of impure coal .... 4 feet
5. Quarry sandstone, massive, light pink, soft, weathering iron-brown...... 60 feet
4. Soft yellowish and reddish sandstones ....100 feet
3. Drab-colored clays with carbonized vegetable matter and gypsum crystals, interbedded with yellow sandstones .... 30 feet
2. Soft yellow and reddish sandstones with some clay layers .... 60 feet

Jurassic.

1. Olive gray, drab or bluish clays with reddish and yellowish sandstones, to base...

This section may be represented diagrammatically as follows:

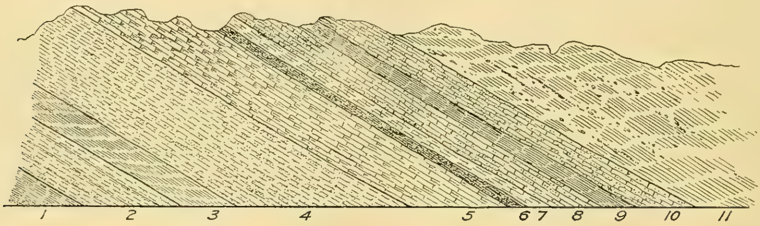


FIG. 4.—Section through Minnekahta Cañon.

1. Jurassic.
3. Equivalent of plant bed in Section No. I.
4. (Upper portion). Equivalent of cycad bed in Section No. I.
5. Quarry sandstone.
7. Dakota leaf bed.
11. Fort Benton.

It will be seen by a comparison of these sections that they are in substantial agreement, although no effort was made to make them so. The crest of the divide in section I represents the Quarry sandstone of section II, which was probably considerably thicker at this point, fifteen feet more being found, exclusive of erosion, but these rocks were often much harder in section I, and no quartzitic rocks were seen in the quarry. On account of the debris thrown down from the quarry and other obstructions, it was not possible to examine the next member below with as much care as was desirable in view of the fact that it seems to be the equivalent of the cycad and fossil forest horizon of section

I; *i. e.*, No. 12 of section I corresponds to the upper 30 feet of No. 4, section II.

At Minnekahta Station, in an ornamental heap of various minerals and rocks from the Black Hills, there were a number of fragments of cycads and fossil wood. We were told that these came from a ridge two miles to the southeast of the station that rises above the Red Beds and shows at its base low buttes and a considerable thickness of Jurassic. This was not visited, but it was evident that the summit of this ridge was formed by the hard sandstone No. 1 of section I (No. 5 of section II), which is continuous to Evans Quarry. The position of the cycad and fossil forest bed here is doubtless the same as on the opposite side of the valley where it was studied.

The occurrence of two other specimens of cycadean trunks, though apparently belonging to a different species, in the same general horizon on the east side of the Black Hills, and of silicified wood in the northern districts, seems to indicate that the same relations obtain on all sides, and this will probably be found to be the case.

The fossil plants of the lower horizon were sent to Professor Fontaine for determination, and the following extracts from his report upon them will show that my interpretation of their significance at the time of their discovery was for all practical purposes correct.

"The best preserved fragments are scattered leaflets, and the summits of the ultimate pinnæ of ferns, which are the parts of those plants which have great value in fixing species. The following are the plants:

"1. The summits of ultimate pinnæ of a fern, which is decidedly like *Asplenium Dicksonianum* Heer, from the Kome beds of Greenland. It has also something of the character of the widely diffused Potomac plant, *Thyrsopteris rarinervis*, but is, I think, nearer Heer's plant.

"2. Some ends of the ultimate pinnæ of a small fern with the facies of a Gleichenia. This is nearest to Heer's *Gleichenia Zippei*, from the same Kome beds, but the pinnules are rather more acute

than most of those of that plant, and indicate that those on this plant, lower down, are somewhat larger than those of *G. Zippei.* The form is also something like *Aspidium heterophyllum*, of the Potomac, but seems to be smaller and more delicate. It may however be the same.

"3. The most common fossils are fragments of detached leaflets and one entire leaflet, of a plant which is strikingly like a Neuropteris of the coal measures (*N. flexuosa*). I am pretty sure, however, that it is a Glossozamites, a form of cycad that has leaflets which, in form and nervation, closely resemble Neuropteris. This, if a Glossozamites, has leaflets proportionately broader and shorter than any known to me, and it is probably new.

"4. There are a number of imprints left by organisms which in shape, dimensions, etc., would agree with fragments of the leaves of Pinus, or of Leptostrobus, but as nothing of the nervation is shown, it is not possible to say which they are. Some of the imprints are too deep and open, apparently, to have been formed by leaves. They seem to have been straight, slender stems.

"It will be seen from this account that the plants, so far as one can judge from such imperfect material, indicate a lower Cretaceous and Neocomian age, with rather more resemblance to the Kome than Potomac phase or grouping, but it is by no means certain that the Potomac grouping is not nearest to that here shown."

Thin sections of some of the silicified wood have been made and microscopically studied by Professor F. H. Knowlton. He reports the results as follows:

"The structure of this wood is very finely preserved, and a glance suffices to show that it possesses the Araucarian type and represents, with little question, an undescribed species of the genus Araucarioxylon. The wood-cells are provided with two rows of alternating hexagonal pores on the radial walls, which nearly, or in some cases, quite cover the walls. The medullary rays are composed of a single layer of thin, short cells, each of which is covered on the radial side with numerous fine dots or punctations. The rays are from one to bout twenty cells high, the average number being perhaps eight or ten. A

large number are composed of only one or two cells. The annual rings are rather indistinct, yet can be made out.

"As far as I now know, only two species of Araucarioxylon have been described from the United States, *A. Arizonicum* Kn., from the Triassic or Lower Jurassic of New Mexico and Arizona, and *A. Virginianum* Kn., supposed at first to belong to the Potomac formation, but now known to be from the Trias of Virginia. These species differ markedly from the one under discussion. With the *A. Arizonicum* it has almost no points in common, while it differs from the *A. Virginianum* in important particulars."

The only sections of the fossil wood that have yet been made were cut from a specimen taken from the cycad bed proper and not from the principal fossil forest, but it often happens that only one species can be found in such a forest. It is therefore probable that the same structure would be shown by the other specimens. I confess to a little surprise at finding that this structure represents the Araucarian rather than the Sequoian type of conifers, since, in the east at least, these two types characterize the Trias and Potomac respectively, no Araucarian specimens having been found in the Potomac and no Sequoian specimens in the Trias. And generally the Araucarian type is more ancient. This evidence therefore points to a lower instead of a higher horizon.

I have made a somewhat careful study of the specimens from the plant bed above Evans Quarry, and have asked Professor Knowlton to assist me, his experience in recently editing Lesquereux's Flora of the Dakota Group having familiarized him with the forms of that age. The result of our joint investigation may be summed up as follows :

The specimens are few and fragmentary, and the only species that can be even approximately determined are :

Asplenium Dicksonianum Heer.
Quercus Wardiana Lx. ?
Lindera venusta Lx.
Aralia Towneri Lx. ?
Virbunites Evansanus n. sp.

The first of these was described by Heer from the Kome beds of Greenland (Gault or Urgonian), but it also occurs in the Atane beds, which are correlated with the Cenomanian and have been supposed to be nearly equivalent to the Dakota Group. It has been found in the Kootanie deposits of British America, in a supposed Neocomian deposit at Cape Lisbourne, Alaska, and in the Amboy Clays at Woodbridge, New Jersey. It is also one of the few ferns that have been found in the Dakota Group, where, however, it is rare. Its evidence, therefore, considered by itself, would be to put even this uppermost deposit in the Lower Cretaceous, but this is overcome by that of the remaining forms. The specimens are the best in the collection, good and characteristic, leaving no doubt on the score of identity.

Quercus Wardiana Lx., is an exclusively Dakota form, but the specimens are too imperfect to make the determination sure.

Lindera venusta Lx., is a characteristic Dakota species, and one of the specimens leaves no doubt as to identity.

Aralia Towneri Lx., is also confined to the Dakota Group, but the specimens, though tolerably good, do not exactly agree, the lobes being too short. They most resemble the specimen figured by Lesquereux in his Flora of the Dakota Group, pl. xxxi, fig. 3, which he doubtfully refers to *Sterculia Snowii* Lx., but which does not at all resemble the type specimens of that species, and probably belongs to *Aralia Towneri.*

The leaf which I name *Viburnites Evansanus*[1] is one of the best preserved in the collection, but it differs specifically from all the forms known to me. It is clearly of the type of *Viburnites crassus* Lx., and *V. Masoni* Lx., of the Dakota Group (Fl. Dak. Gr., pp. 124, 125; pl. xlv), but is longer in proportion to its width with a larger number of secondary nerves, which are irregularly disposed, the angle differing on the two sides of the midrib, as do also their number and proximity. The branching is strictly dichotomous and the finer nervation is distinct. The margin is only preserved near the summit, but here it is that of *V. crassus.*

[1] For Mr. Fred. Evans, proprietor of Evans Quarry, founder and leading citizen of Hot Springs, who greatly aided and facilitated the expedition.

It thus appears that the flora of the beds above Evans Quarry is distinctly that of the Dakota Group, while all the plants found below that horizon as distinctly indicate a Lower Cretaceous age. The force of this evidence is to my mind irresistible, and it is safe to predict that if any other paleontological evidence is ever found it will confirm this conclusion. The question still remains as to where the dividing line is to be drawn. Between the cycad and fossil wood horizon and that of the Dakota leaves there are some hundred feet of sandstones and shales. Sixty to seventy-five feet of this consists of the massive or heavy-bedded building stone, which in places becomes flinty and very hard. As the thin shaly layer which separates this from the leaf bed may be safely put with the latter into the Dakota proper, and there seems no reason for separating the similarly constituted layer that intervenes between the cycad horizon and the base of the sandstone from the one upon which it rests, the question is narrowed down to that of the position of the quarry sandstone. That question I will leave to the stratigraphical geologists.

As to where in the Lower Cretaceous series the basal portion of the Cretaceous rim of the Black Hills should be located, it can only be said that the cycadean trunks elsewhere found in North America have all come from well down in that series or else from the Upper Trias. Leaving the latter cases out of the account we have the Maryland specimens and the one from Kansas. It was long supposed that the Maryland specimens were derived from the Iron Ore Clays, which were referred by McGee and Fontaine to an "Upper Clay Member." This is now known not to be the case, and it has been demonstrated that the cycads occur in the basal sands at the same horizon as the Sequoian trunks, and probably the same as the Rappahannock freestone, which has yielded more fossil plants than any other horizon. Whether this is the same horizon as that of the James river, where cycads and conifers prevail and no dicotyledonous leaves have been found, or a somewhat higher one, need not now be discussed, as the whole subject will soon be thoroughly presented along with the evidence. Certain it is that the Potomac

cycads belong to the lower part of that formation. The Kansas specimen is confidently referred by Professor Cragin to the Trinity Group of the Comanche series of Hill, which forms the lowest division of that series. Professor Hill is disposed to accept this conclusion, and Professor Prosser of Washburn College, Topeka, sees no reason to doubt its accuracy.

The other plants, as has been seen, occur about one hundred feet below the cycad bed. Professor Fontaine's report above quoted places their significance in its true light and leaves little to add. The occurrence of *Asplenium Dicksonianum* shows simply that this common form persisted in the same area through a long period. But this it was already known to do. Should it, however, prove to be the *Thyrsopteris rarinervis* Font., it would be a characteristic lower Potomac species.

The forms that Professor Fontaine refers to Glossozamites argue entirely for a Lower Cretaceous or even earlier age. Eight species of that genus are known, ranging from the Upper Trias to the Urgonian. Some are from the Lias, but most of them are found in the Wealden and Neocomian. They had a wide geographical range, occurring in Greenland (Kome beds), India (Damuda series), and in various parts of Europe. One species, *G. distans*, is from the lower Potomac of Fredericksburg, Virginia.

Gleichenia Zippei (Corda) Heer was first described by Corda, who referred it to Pecopteris, from the Gosau formation of Bohemia, supposed to be above the Cenomanian. It has since been found in the true Cenomanian of Bohemia and in the Quadersandstein of Germany. Heer found it in all the Cretaceous beds of Greenland (Kome, Atane, Patoot), also in the Cretaceous of Spitzbergen. Newberry detected it in the Amboy Clays. It varies considerably, and the name may include more than one species. Fontaine compares the Black Hills specimens only with Heer's Kome forms, and is not certain that they may not rather represent his own *Aspidium heterophyllum* from the Lower Potomac of Fredericksburg. The evidence afforded by this species, therefore, is not strong, but it certainly does not occur in the Dakota Group elsewhere so far as known.

Leaves of Pinus and Leptostrobus occur quite frequently in the Potomac formation in Virginia, Alabama and New Jersey, but have never been found in the Dakota Group. So far, therefore, as these forms from the Black Hills go they favor the view that the bed in which they occur is Lower Cretaceous.

The chief argument from the plants is that they were all of humble types, no dicotyledonous leaves occurring among them. The force of this argument may be appreciated when it is remembered that the flora of the Dakota Group, one of the richest fossil floras of the world, consists, as now published, of 460 species, of which 429 are Dicotyledons. There are only 6 ferns, 12 cycads, 15 conifers and 8 monocotyledons. The cycads are only known by fragments of fronds or pinnæ, and a few doubtful fruits. The chances are hundreds to one that any plant bed of that age will contain dicotyledonous leaves in profusion, and the lower forms very sparingly, if at all. This was found to be the case at the real Dakota plant bed above Evans Quarry. Only one fern was obtained, while leaves were abundant though difficult to secure entire with the insufficient appliances with which we were provided.

A closing word on the bearing of these facts upon the Lower Cretaceous of North America may be permitted. It would seem probable that a considerable portion of the deposits underlying the marine Cretaceous of the Rocky Mountain region which have heretofore been referred to the Dakota Group on purely stratigraphical evidence may really be much older. When in 1883 I descended the Missouri River from the mouth of Sun River to Bismarck, most of the way in a "mackinaw," and in company with Dr. C. A. White, that able geologist was of the opinion that the rocks at the Great Falls of the Missouri belonged to the Dakota Group. They were seen distinctly passing under the Fort Benton shales below, and there were no more indications of a division line at any point in the series than Professor Newton found in the same section of the Black Hills. As no Cretaceous older than the Dakota Group was at that time supposed to exist in that region, it was natural to refer all below the Fort Benton to

that group. But when a rich plant bed was at length discovered at Great Falls it was found to belong to the Kootanie group of Dawson, as developed in regions nearly north of this point. Here then is another series in which the dividing line between the Upper and Lower Cretaceous has to be found.

It would, perhaps, be rash to predict that like conditions will be found to prevail at most points along the slopes of the Rocky Mountains, but the facts are sufficient to constitute a good working hypothesis, and a systematic search at various points in the rocks that overlie the Red Beds and the Jurassic wherever these occur may result in further valuable discoveries. One additional fact that points in this direction may be noted. There was picked up on the surface within the Laramie terrane at Golden, Colorado, a segment of a small cycadean trunk which Lesquereux called *Zamiostrobus mirabilis*, but which has been sent to Count Solms-Laubach, Professor of Botany at the University of Strasburg, and the leading authority on the subject, and pronounced by him to be a trunk and not a cone (as, indeed I had myself previously stated),[1] referable to the genus Cycadeoidea. This region, as most geologists know, lies at the foot of the Front Range, and marine Cretaceous passes under the Laramie at Golden. The several members of the Cretaceous, in descending order, would naturally be found in passing up the adjacent slope, and if a horizon yielding cycad trunks occurs here it would be very natural that some of these cylindrical trunks should roll down the steep escarpment and be arrested on the plain below where this specimen was found. This explanation is far more probable than that this form could have grown in Laramie time, though no one can say that this is impossible, especially as the specimen is a diminutive one and may represent the degenerate descendants of the robust forms of the Lower Cretaceous.

Whatever future consequences may grow out of the discoveries recorded in this paper they at least, in and of themselves, constitute a fresh contribution to our rapidly growing knowledge of one of the hitherto least known periods of North American geology, to wit, the Lower Cretaceous.

LESTER F. WARD.

[1] Science, Vol. III., p. 533 (1884).

ON DIPLOGRAPTIDÆ, Lapworth.[1]

In the fall of 1888, H. Munthe brought from Bornholm a piece of Baltic sea limestone[2] [Ostseekalk] with graptolites, which he kindly gave me, as I was at work on the Silurian region of the Bothnian sea. From this piece, half the size of one's fist, I have obtained, by the aid of muriatic acid and vinegar, several hundred pieces of a *Diplograptus*. As this compact limestone is excellently qualified to preserve the very finest details, the fragments, which consist mainly of proximal-ends and siculæ, furnish excellent material for the examination of the inner organization of this particular *Diplograptus*.

These remains are of a half-carbonized, chitinous substance, and after separation were dark brown and almost opaque, therefore I treated them with Schulze's maceration medium by which their color was changed to light brown or yellow. After careful washing with water, they were further treated with alcohol and oil of cloves, and were then preserved in the ordinary way in Canada balsam.

According to the present acceptation, as recorded in general hand-books of paleontology,[3] and in the main the same as that given by Lapworth[4] as early as 1873, the family *Diplograptidæ*, Lapw., is characterized as follows: Hydrozoma, consisting of two branches united dorsally, between which the scicula is imbedded, its broadest portion forming the proximal end of the hydrozoma.

[1] Extract from Bulletin of the Geological Institute of Upsala, Vol. I, No. 2, 1893. Translated from the German by Charles Schuchert.

[2] C. Wiman: Ueber das Silurgebiet des Bottnischen Meeres, I, p. 73, Bull. Geol. Instit., of Upsala, Vol. I, No. 1, 1893.

[3] K. A. Zittel: Handbuch der Palæontologie, Abtheilung I, Band I, 1876-1880. H. A. Nicholson and R. Lydekker: A Manual of Palæontology for the use of students, Part I, Third Edition, 1889.

[4] Notes on British Graptolites and their Allies, I.—On an improved Classification of the *Rhabdopora*, Parts I and II, Geol. Mag., Vol. X, pp. 500, 555, 1873.

Since in fact the graptolites are generally compressed and altered into a metallic sulphide, or are otherwise poorly preserved, and as this was also largely the case with the material examined by Lapworth, the genus *Diplograptus* was referred to the *Diprionidæ*, mainly by a comparison with other forms, particularly *Didymograptus* and *Dicranograptus*.

In 1876, Lapworth[1] described two species of a new genus, *Dimorphograptus*, and, because of these, doubted the existence of any diprionidian forms. The proper view, he believed, was that the scicula in all graptolites develops but one bud. This view (an opinion founded on fact) that a monoprionidian scicula which at first gives off a monograptus-like hydrosoma could really give origin to a complete diplograptus-like distal end, has in later literature never been considered, but the older idea has been persistently retained to the present time.

The Scicula. In the present material, this is represented by 168 specimens, and of these 85 are separate. The form of the scicula is given in Pl. II., fig. 1-5 and 7-9. It is divisible into two essentially different parts, the distal one having a very thin and transparent wall, while the proximal is thicker and less transparent. Along the wall of the distal part are longitudinal thickenings or lines which branch and anastomose basally, and are lost near the boundary with the proximal portion. They unite, however, in the point of the scicula, and form the distal portion of the virgula to which I will again refer. Between the two parts of the scicula there is no septum.

In the proximal part of the scicula can be seen closely arranged diagonal lines, which I regard as growth lines. These have the same appearance as the often described thecal lines, differing only in the fact, that at a certain distance from the virgula, they gradually bend downward to join it at a sharp angle. In the very oldest part of the proximal portion of the scicula, the lines round regularly (Pl. II., fig. 1), since the virgula, when these were forming, was not yet present. Very soon, however, they begin to exhibit a slight downward bending, and this increases

[1] On Scottish *Monograptidæ*. Geol. Mag., Decade II, Vol. III, p. 544, 1876.

line for line until the virgula begins to show, and practically absorbs the lines. The angle at which the lines and the virgula unite diminishes with age. The mature scicula is provided with three spines at its aperture, one of which is the cylindrical virgula. The other two are flat, and should probably be termed lobes. They have that appearance, as shown in figure 5, and are situated opposite the virgula on each side of a shallow emargination of the aperture, joined by a slight swelling of the border of the indentation.

The form and completion of the aperture gives the scicula a particularly conspicuous bilateral symmetry, on account of which the animal at this stage recalls a bryozoan rather than a modern hydroid polyp.

The Theca. Before the scicula has matured, there forms, at the point illustrated in Pl. II., fig. 4, the beginning of a second tube, which is also provided with growth lines. The circular perforation by which it communicates with the cavity of the scicula has been observed in forty-one examples. This opening is not produced by absorption of the wall as shown by the slight irregularity of the scicular growth lines at the origin of the second tube (Pl. II., fig. 4). This tube does not develop into a general canal or similar part, but forms the first theca. Then from this one chamber of habitation there simply develops a second.

The first theca (Pl. II., figs. 4, 5) at once leans closely on the scicula, widens very rapidly, approaches toward the virgula, and in bending around the scicula passes it, so that the theca comes to lie on the back (dorsal) side[1] of the scicula, and eventually both increase at an equal rate towards the proximal end. The growth lines of the first theca like those of the scicula, although in a less degree, are also drawn along, so to speak, by the virgula. As soon as the theca, which clings closely to the virgula, has grown a little further than the scicula towards the proximal end, it again changes its direction, and bends outward and eventually upwards. Where it begins to grow upwards, it gives off from one to three spines in succession, which start with a slight emar-

[1] I have named that side the front which in figures 4 and 7, faces the observer.

gination of the wall, and appear to develop like the spines of mollusks. In one example (Pl. II., fig. 6), two approximate spines are joined by a thin skin. Therefore there are from four to six spines on the proximal end of this *Diplograptus*.

A second large hole opens on the first theca towards the front side (Pl. II., fig. 4). On the back side (Pl. II., fig. 5), the lines are disposed parallel with its margin; on the front, however, they converge. From this opening comes the second theca (Pl. II., fig. 7), on the right side in front of the scicula. Shortly after it has left the first theca, the turning of the hydrosoma must have taken place; *i. e.*, both thecæ now begin to grow in an opposite direction and thereby change the direction of the aperture towards the distal end. Further scicula growth probably ceases at this stage of development. The newly-formed theca fastens itself to the forward spine on the right side of the scicula.

The second theca hardly has left the first when it gives origin to the third, which also lies on the first, and is therefore situated on the left side. The pore uniting the third theca with the second is situated a little more proximally than that which joins the second with the first. The earliest budding of the third theca, therefore, occurs between the origin of the second and the turning of the hydrosoma. Its lower part fills the space in the bend of the first theca (Pl. II., fig. 8).

In my material occur many specimens having only the scicula, the first two thecæ, and the proximal portion of the third. If such an example were pressed flat without relief, and changed into pyrite, it would be recognized as a scicula having two buds with a common canal. The third theca increases only at the distal end. From it, the fourth theca takes its origin, and is situated in front of the scicula on the right side of the hydrosoma (Pl. II., fig. 8).

Even if the openings between the first and second and the second and third thecæ were not apparent, but only the origin of the first theca from the scicula and the fourth from the third were observed, the following law for the formation of the thecæ could be deduced: Each theca has its origin in the next on the

opposite side of the hydrosoma. The alternating of the thecæ, therefore, is not only governed by the greater space attainable, but by the age and origin of the thecæ as well. In certain respects this law is also true for the scicula which may be regarded, if desirable, as the primary theca.

The growth lines meet on the outer edge of the hydrosoma in such a way as to produce a zig-zag line (Pl. II., fig. 7). This is probably produced by the same cause as the marking of the lobes of the scicula. Analogous to these, also, are the well-known paired spines of the thecal apertures of certain diplograptids, which are likewise an expression of the bilateral symmetry of the thecæ.

The partition wall between two adjoining or opposite thecæ is naturally double, and exhibits a slight thickening on the proximal inner edge.

The angle between the median line of the hydrosoma and the double partitions of the thecæ is greater in the distal portion, (25°-30°) than in the proximal, where it is occasionally zero.

An examination of figures 8 and 9 shows that the scicula originally lies outside of the hydrosoma, except for the loose adherence of the thecæ, being united to it only at the termination of the first theca. Nevertheless the earliest thecæ are indented on the dorsal side and partly enclosing the scicula, so that it appears to lie in a depression of the outside of the hydrosoma. The thecæ extend more and more over the scicula until the central space is nearly transformed into a tube encircling the scicula, and when the fifth theca, *i. e.*, the third on the same side as the first, finally opens, the scicula then disappears into the hydrosoma (Pl. II., fig. 9). The place where the scicula comes in contact with the perforated wall of the hydrosoma lies beneath the boundary between the two parts of the scicula (Pl. II., fig. 9).

The Virgula. As the virgula has been observed to occur within, and protrude from, both ends of the hydrosoma, it has been naturally concluded that the virgula passed without interruption through the entire hydrosoma. This, however, is not the case (Pl. II., figs. 1-3). The origin of that portion of the virgula which lies in the left wall of the proximal part of the

scicula has been already described. This part like the scicula grows towards the proximal end. The distal portion of the virgula does not begin to develop until the scicula has been taken into the hydrosoma. It is likewise stouter the further it is removed from the point of the scicula. As it has its origin in the union of the longitudinal lines of the distal portion of the scicula, it appears very probable that the entire distal part of the scicula, also, first had its inception when the scicula is taken into the hydrosoma. Accordingly, the scicula, when it was yet free, would have been either open on the distal end or it had a very thin wall which disappeared later. The first shell-layer, therefore, was a small simple ring.

Here and there, quite irregularly, the virgula fastens itself to the above-mentioned swellings on the proximal ends of the thecal partitions (Pl. II., figs. 11-12). In figure 10, it is entirely free. In diagnoses of diplograptids, it is often mentioned that the virgula extends beyond the distal end. This need not be accidental in a species of this nature, since in forms where the virgula is not fastened to the diagonal swellings, it has a greater chance of being preserved, even if the periderm is broken away. If the virgula is regularly attached to every partition, it can only become protruding under very favorable circumstances. In this species, I did not see the virgula protruding.

A common canal as progenitor for all thecæ does not exist. The partition walls between the thecæ, moreover, join so closely on the center of the hydrosoma that the virgula hardly has sufficient space to straighten itself.

A longitudinal septum is not present.

In summing up the results of my investigations, the following points are shown :

1. The scicula consists of two parts, is basally open, and bilaterally symmetrical.

2. From the scicula there sprouts but *one* bud. This *Diplograptus* is therefore monoprionidian.

3. This bud does not develop into a canal, but into a theca.

4. Each theca comes forth from the next more proximally

situated theca of the opposite side, and not from a common canal.

5. The hydrozoma including the virgula has grown in two opposite directions.

6. The scicula is not imbedded between two branches grown together, but is free originally, and later is incorporated within the periderm.

7. The virgula is not double, and has two quite distinct phases of development.

8. To the virgula are occasionally attached the bases of the thecal partitions.

9. A common canal as progenitor of the thecæ does not exist.

10. A double longitudinal septum is not present.

It is not now my intention to assert that this organization is repeated in all the representatives of the family *Diplograptidæ*, for so little of their internal structure is yet known, they may have a collection of remotely related forms with thecæ arranged in two rows, but since this family is entirely or in the main a natural one, the deviation from the general plan of structure cannot be very great.

Eight days after I had announced the above before the geological section of the Student's Natural History Society, and after I had nearly finished writing it, I received from S. L. Tornquist a copy of his work "Observations on the structure of some *Diprionidæ*." Särtryck af Kongl. Fysiografiska Sälls Kapets Handlingar. Ny följd 1892-3, Bd. 4, Lund, 1893. Lund Univ. Årsskrift, tom XXIX.

The "connecting canal," which, according to Tornquist, unites the scicula with the "common cavity of the rhabdosoma," is that part of the first theca which grows downwards. The proximal end of *Climacograptus scalaris*, Lin., figs. 7–15, and 18-20, *C. internexus*, Tqt., fig. 25, *Diplograptus palmeus*, Barr., figs, 29, 33–35, and *Cephalograptus cometa*, Gein., figs. 39–41, show the identical structure which I have just described. The groove illustrated in figure 17 and mentioned on page 6 as "a narrow longitudinal groove as to the nature of which I am not

able as yet to offer any satisfactory explanation," can be, since it terminates before it reaches the point of the scicula, nothing else than that portion of the virgula which lies in the wall of the scicula.

Tornquist nowhere says that the described species are monoprionidian, but this can be clearly seen in the figures 39-41 of *Cephalograptus cometa*, Gein., and if those just cited are compared with my own, there can be no doubt that the species above mentioned are also monoprionidian.

It is particularly interesting to note that the presence of a longitudinal septum does not depend on the diprionidian character of the *Diplograptidæ* as generally accepted.

EXPLANATION OF PLATE.

The figures have been drawn about twice the size of the scale, with Zeiss and Abbe's drawing apparatus. The shading was obtained by still greater enlargement, and by various accessories to the microscope. The given scale does not apply to figure 10.

Fig. 1. Young scicula; dorsal side. × 37.

Figs. 2-3. Adult scicula; front view. The thecæ are removed. 37–1.

Fig. 4. Form and place of the first theca and the perforation from which the second will come; front view. × 37.

Fig. 5. The same; dorsal view. × 37.

Fig. 6. The first theca with three spines, two of which are united by a thin skin. × 37.

Fig. 7. Form and position of the second and third thecæ; front view. × 37.

Fig. 8. Form and position of the fourth theca and imbedded scicula. × 37.

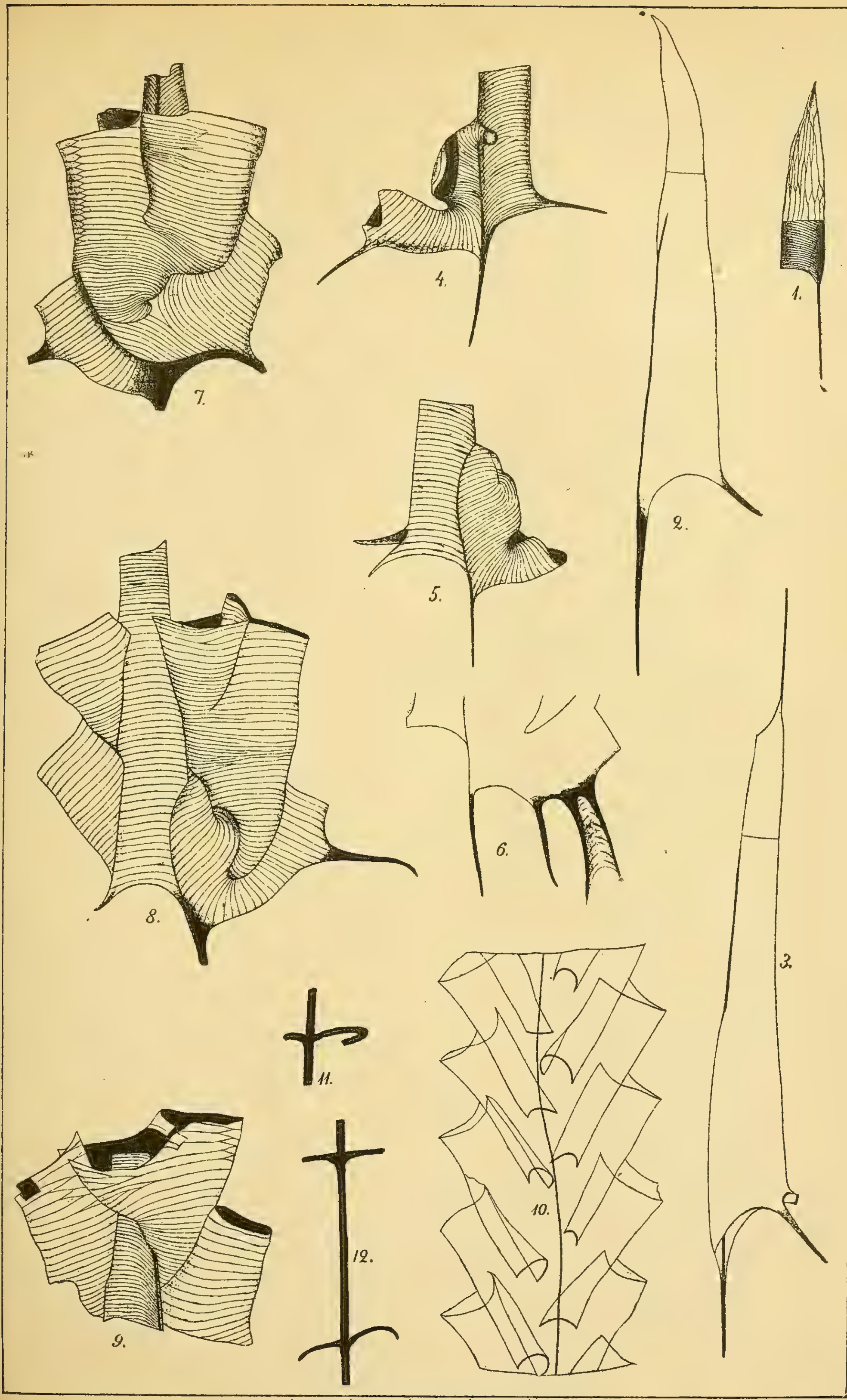
Fig. 9. Incorporation of the scicula in the hydrosoma. × 37.

Fig. 10. Distal portion. The transparency partially made use of. The virgula is wholly free. × 13.

Figs. 11-12. Attachment of the proximal edges of the partitions to the virgula. × 37.

The material is in the collection of the Geological Institute at Upsala.

CARL WIMAN.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GEOLOGICAL SURVEYS IN ALABAMA.

First Survey.

UPON the appointment of Professor Michael Tuomey, in 1847, to the professorship of Geology in the University of Alabama, it was made a part of his duty to spend such portions of his time, not exceeding four months in each year, in exploring the state in connection with his proper department, as the Trustees might consider for the advantage of the state. Professor Tuomey, in accordance with these instructions, began immediately his explorations, and thus the first systematic examination of the geology of Alabama was instituted. Such extracts from his reports to the Trustees upon this work as were considered of general interest, were published from time to time in the newspapers of the city of Tuscaloosa, and in January, 1848, the state legislature made recognition of this effort by appointing Professor Tuomey State Geologist, and requesting him to lay before them the results of his explorations, to be published by the state. Thus was begun the first geological survey of Alabama. From 1848 to 1853 Professor Tuomey continued these explorations at the expense of the University of Alabama, the state having made no appropriation for the purpose, and in 1849 he presented to the legislature his first biennial report, which was published in 1850 by the state. The geological map was not ready, however, for distribution with the report, and appeared separately. When we consider the great number of observations recorded in this volume, and the accuracy with which the limits of the various geological formations were laid down upon the map, after only two years' exploration, in a state about whose geology almost nothing was previously known, we cannot fail to recognize the genius of the man.

In 1854 the legislature passed a law appropriating $10,000 for the support of the Geological Survey, and an additional sum

of $2,500 per annum for the salary of the state geologist. Under this law Professor Tuomey was appointed State Geologist by Governor Winston, resigned his position in the University, and devoted his whole time to the survey till about 1856. During the two years, however, of his service to the state he still kept his office at the University of Alabama, and delivered lectures to some of the classes of that institution. During this time he was assisted by Professor E. Q. Thornton, O. M. Lieber and others, and in 1855 Professor John W. Mallet was appointed Chemist to the survey. The results of the labors of Professor Tuomey and his assistants were brought together by him in a report which was submitted to the legislature in November, 1855, but, by the negligence of the state printers, and for other reasons, the publication of this report was delayed for more than two years. The appropriation for the survey being exhausted, Professor Tuomey resumed his work at the University in 1856, intending to devote his leisure time as before to the survey, and especially to the elaboration of his notes. The summer of 1856 was devoted to field work, but his death occurred the following year 1857, on March 30.

Upon the death of Professor Tuomey, Dr. Mallet undertook the task of editing and bringing out the long delayed report It was found that part of the manuscript had been lost, some of it was incomplete, and thus a large amount of valuable material was lost to the state and to science. In September, 1858, this Second Biennial Report at last appeared, accompanied by another map of the state, more detailed than the first. After the death of Professor Tuomey, in 1857, the survey was discontinued.

From 1868 to 1876 a Commissioner of Industrial Resources was one of the regular officers of the state government, and four small pamphlets were issued from that office, but the Legislature of 1874–5 practically abolished the office by making no appropriation for the salaries of the Commissioner and his Assistant, and in the code of 1876 no provision was made for the continuance of the Bureau.

Second Survey.

First Decade.—In the meantime, upon the reorganization of the University of Alabama, in 1871, after a "reconstruction" régime of five years, the Board of Regents of that institution again took the initiative in re-establishing the Survey by requiring the Professor of Geology to devote as much time in traveling over the state, in making examinations and collections in geology, as would be consistent with his duties at the University.

In pursuance of this ordinance, the present writer, who at that time filled the chair above mentioned in the University, spent a part of his vacation in 1871, at his own expense, in the examination of certain marine Tertiary deposits in Clarke, Washington and Choctaw counties.

The subject of the Geological Survey was brought before the legislature of 1872–3, and an act was passed by them in 1873, reviving the survey, naming Eugene A. Smith, State Geologist, and making an appropriation of $500 per annum for the expenses of the survey, and an additional appropriation of $3,000 for an outfit for chemical laboratory, and traveling and camp equipments. In 1877 a bill was passed making a biennial appropriation of $200 for the purpose of preparing maps and other illustrations for the geological reports. Another special appropriation of $250 was made in 1879 for the same purpose.

During the ten years from 1873 to 1882 inclusive, the writer devoted the greater part of the three months of each summer vacation to geological excursions, receiving no compensation therefor in the way of salary. The actual traveling expenses were, however, defrayed out of the annual appropriation of $500, which also paid the other contingent expenses of the survey. In the summer of 1878 Mr. Henry McCalley, at his own expense, accompanied the writer in the field, and during the following years, from 1879 to 1882, he undertook independent field work, without compensation from the survey beyond the payment of his expenses while in the field. At this time he held the position of Assistant in the Chemical Department of the University, then also under the charge of the present writer. There were other

volunteer assistants during this time; the two whose contributions are to be found in the survey reports being Professor W. C. Stubbs, who made a number of chemical analyses, besides taking part in the field work, and Mr. T. H. Aldrich, who prepared a valuable sketch of the early history of coal mining operations in Alabama, published in the report for 1875.

Publications.—During this period of ten years there were published four annual reports, viz., for 1873, 1874, 1875, and 1876, and three biennial reports, viz., for 1877–8, 1879–80, and 1881–2.

With the exception of the Agricultural report of 1881–2, these were of the nature of preliminary or reconnoissance reports, and they deal chiefly with the economic features of the state. The report for 1873 was a mere statement of the plan of the work proposed. That of 1874 is concerned with the crystalline region, and particularly with the copper-bearing strata. At the time when the examinations were made there, the whole section was greatly interested in the subject of copper, just as now it is interested in gold. A part of the next report, 1875, treated of the same subject, but the greater part of it was devoted to the examination and classification of the Valley formations, of Jones' Valley and the great Coosa Valley region. Professor Tuomey recognized the occurrence in these valleys of the Silurian, Devonian, and Subcarboniferous formations, without undertaking the subdivision of the same, except in the case of the Clinton and Trenton. During the summer of 1875, it was possible for the writer to establish the practical identity of these formations with what had already been so clearly described for Tennessee by Professor Safford, and he established the fact of the existence in Alabama of the Ocoee, Chilhowee, Knox Sandstone, Shale and Dolomite, the Lower and Upper Subcarboniferous with their respective minor divisions. The report for 1875 contained also the sketch of the early history of Coal Mining in Alabama, to which reference has already been made above, and there were also presented the records of the borings by diamond drill in the different parts of the Warrior Field together with an attempt at correlating the same. The report holds also many details of the

occurrence and composition of iron ores and limestones of this district. The report for 1876 continued the examination of the valley regions, and contained a paper on the Alabama fresh water shells by Dr. James Lewis, contributed by Mr. Aldrich.

In 1877–8 attention was turned to the Warrior Coal Field, till then comparatively unknown, and maps were published of Walker, Fayette, Marion, and Winston counties, which were practically underlaid with Coal Measures. Notwithstanding the fact that no coal was mined at that time in all this region, and it was not possible with the means at the disposal of the survey to open the seams so as to show their true value, the publication, especially of these maps, turned the attention of investors to these counties, and the next few years witnessed marvellous developments there.

In 1878–9 a movement was set on foot to secure an appropriation from Congress for the purpose of making navigable the Upper Warrior river to develop the coal seams along its course, and the writer, with Mr. McCalley and Mr. Jos. Squire, ran a line of levels from the forks of the Warrior down to Tuscaloosa, and made special re-examination of the coal seams within available distance from the river. The expense of this survey was borne chiefly by the War Department, but the map and report were published by the survey. In this document the details of the coal seams were given with a much greater degree of fullness than heretofore, together with many facts bearing upon their stratigraphical relations. In this volume was also a continuation by Mr. McCalley of the description of the Tennessee valley, begun the year before by Mr. McCalley and myself; together with the analyses of some 50 specimens of coal from the Warrior field.

In 1880 the writer was requested by Dr. Hilgard to prepare for the Tenth Census a report on Cotton Culture in Alabama and Florida, and in 1883 was published the state report, embracing the results of these observations in Alabama. In addition to the special descriptive matter, this report contains a general discussion of the composition, mode of formation, and properties of

soils and of the changes produced by cultivation. The maps showing the agricultural divisions of the state, and showing the relations between the area cultivated in cotton and the total area, were prepared for the Tenth Census, but the survey had the privilege of using the plates. The other illustrations were prepared by the survey. This report deals in some detail with the agricultural divisions of the state, and contains many analyses of soils and marls, made partly by the Census and partly by the geological survey.

In the case of the two reports last named, advantage was taken of opportunities in which work done by the writer for other organizations could be turned to the direct benefit of the survey, thus securing much fuller reports and better illustrations than would have been at all possible with the survey funds alone.

Cost.—The printing of these reports was paid for out of the general printing fund of the state, at a cost of $6,750, and this, added to the $8,000 directly appropriated to the survey for equipment, field work, and all other purposes, gives $14,750 as the total cost of the survey during these ten years; an average of $1,475 per annum.

Before going further, it may be well to consider what was accomplished during this decade, to point out the advantages derived from this long period of preliminary work, and to call attention to some of its manifest disadvantages.

1) Every county in the state was visited, and the main features of the geology and resources of each were ascertained; descriptions were published of each of these counties, in some cases giving much detail; the main subdivisions of the geological formations in the state were established; the mode of occurrence and general distribution of the most important mineral resources were described and illustrated by many analyses; and the agricultural features of the entire state were given with an approach to completeness, thanks to the coöperation of the Tenth Census.

2) The experience and the knowledge of the territory acquired

by the state geologist during this long period, have unquestionably since been of benefit to the state, for without such experience on his part the disbursing of large sums and the directing of the work of the enlarged survey, so as to secure the best results and to avoid injudicious expenditures, would have been attended with many perhaps insurmountable difficulties. I might add further that the cost to the state of this preliminary work, as shown above, was small.

3) On the other hand, while at the beginning of the work these preliminary reports supplied in a measure the information then demanded, it cannot be denied that the progress of the state in the development of its great resources, especially in the latter part of this period created a demand for much more detailed and special information in certain directions than the survey could supply without some greater expenditure of money.

Second Decade.—Accordingly, a bill was brought before the General Assembly of 1882–83, providing for an annual appropriation of $5,000 for the ensuing ten years, and this bill became a law in February, 1883. Before the expiration of this ten-year limit the amount of the annual appropriation was increased in 1891 to $7,500; to continue till otherwise ordered by the General Assembly, thus avoiding the necessity of renewed legislation at every meeting. Under these laws assistants were appointed and work assigned as follows. Henry McCalley, in the Warrior Coal Field and subsequently in the Valley regions; Jos. Squire, in the Cahaba Coal Field; A. M. Gibson, in Murphree's Valley and the Coal Measures adjacent thereto, and afterwards in the Coosa Coal Field; the State Geologist, with D. W. Langdon, T. H. Aldrich, and L. C. Johnson, undertook the examination of the Cretaceous and Tertiary formations of the Coastal Plain. Administrative work, the editing of reports, and the preparation of the Geological Map, have however engrossed a great part of his time. Later, Dr. George Little made an examination of the clays of the Lower Cretaceous; Dr. W. B. Phillips began the investigation of the Gold region, and Mr. K. M. Cunningham has demonstrated

the existence of true chalk deposits in our Cretaceous formation.

Geological Reports published or in preparation.—Departing from the strict chronological order we shall state briefly the work accomplished and in hand in each of these divisions.

In 1886 was published McCalley's Report on the Warrior Coal Field, containing detailed sections of all the exposures of coal seams in the basin division of this field, together with Mr. Gibson's account of part of the plateau division. This report also contains the first approximately full columnar section of the measures of this field. In 1891 appeared McCalley's report on the Plateau region of the Warrior Field with map and colored sections. Mr. Gibson also contributed to this volume.

Active work has also for the past three years been going on and is still in progress under Mr. McCalley's direction in the Warrior Basin, in locating accurately the surface outcrops of the important coal seams. His examination of the Valley regions and their economic products, including iron ores, limestones, building stones, and bauxites, has been in progress for the past five or six years, and his report thereon is in great part written up.

In 1890 was published Mr. Squire's Report and Map of the Cahaba Coal Field. This document is the outcome of about thirty years'work, during which time Mr. Squire has been continuously engaged in this field either in active mining or in making instrumental surveys for individuals or corporations, all the results of which have been incorporated in his report. The map shows accurately the surface outcrops of all the important seams of coal, and a number of carefully constructed vertical and horizontal sections of the field. It exhibits also the geology of the adjacent valleys, compiled mainly from Mr. McCalley's notes by the present writer, who has also added a description of these formations and a sketch of their accumulation and subsequent history.

In 1884 the existence of phosphatic nodules and marls was discovered. The distribution, quality, and quantity of these materials were pretty thoroughly investigated by Mr. Langdon and myself, to form part of the coastal plain report; but the holding

back of this report for the map, and on account of active work in progress in the lower part of the state which it was desirable to incorporate therein, led us to issue in 1892, as Bulletin No. 2, an account of these marls in separate form.

In 1893 appeared Mr. Gibson's report on the Geology and Resources of Murphree's Valley, the publication of which had been delayed on account of the lack of a suitable map for its illustration. His report on the Coal Measures of Blount Mountain has just been published, 1894, and he is at work upon a preliminary report on the Coosa Coal Field.

Dr. Wm. B. Phillips, in 1891, undertook the examination of the gold region, spent part of one summer in the field work, and prepared a partial report thereon, but was unable to complete this work, and it was taken up in 1893 by myself and Mr. W. M. Brewer. It has been conclusively shown that these fields, with suitable methods of extracting the gold, can be worked in many places at a profit. The great activity now prevailing there leads us to think that the mining of gold will soon take an important place among the industries of the state.

Coöperation of the U. S. Geological Survey. Soon after the consolidation of the United States Geological Surveys into one organization in 1879, propositions were made by the director for coöperation with the state surveys, in accordance with which it was agreed that the U. S. Survey should make in Alabama accurately measured sections of our Paleozoic formations at two points selected after full consultation. This plan was afterwards slightly modified, and the results were published in 1892 as Bulletin No. 4 of the State Survey, a Report on the Geology of Northeastern Alabama and the adjacent parts of Georgia, by C. W. Hayes. This region in Alabama had already been pretty closely examined by the state survey, so that the change in the original plan caused some degree of duplication of work, but the mode of treatment of the subject and the map showing the connection with Georgia make this an exceedingly acceptable contribution.

Another result of this coöperation was a trip in 1883 down

the Warrior and up the Alabama rivers, made by L. C. Johnson and myself at the joint expense of the State and National Surveys, during which we collected the data for the first attempt at the stratigraphy of the Cretaceous and Tertiary formations of our Coastal Plain. The greater part, however, of the material afterwards brought together by the writer and published as Bulletin No. 43 of the U. S. Survey was collected in the following seasons, 1884–5–6, by the Alabama survey alone, by Messrs. Langdon, Aldrich and myself. Mr. Langdon afterwards carried these examinations across the state to the Georgia line, and thence down the Chattahoochee to Bristol, Fla., when he made the discoveries of the Chattahoochee and Alum Bluff series of Miocene formations, which have since become famous localities.

Although the joint trip of the present writer and Mr. Johnson, above mentioned, occupied only two weeks' time, Mr. Johnson was afterwards assigned by the U. S. Survey to independent work in this territory, especially in the examination of the post-Eocene formations, and it is to his work that we owe the greater part of our knowledge of the Grand Gulf and Pascagoula Miocene of this state. Mr. Johnson was also for one season in the employ of the state survey in completing the work thus begun. The present writer has also spent an additional season in this territory in 1891, and the coastal plain report above alluded to will contain the notes from all these sources.

It was feared by many that the extension of the U. S. Survey into the territories of the older states would have the effect of preventing the organization of new state surveys, and of causing the discontinuance of those already in existence, but the continuance or completion of existing surveys in New Jersey, Minnesota, Illinois, Indiana, Pennsylvania, Kentucky, Alabama and Wisconsin, and the organization of new surveys in Texas, Arkansas, Missouri, Georgia, North Carolina and Iowa show that these fears have not been fully realized. The national and state surveys occupy practically somewhat different ground, and so far from being antagonistic, they should be mutually helpful. In the case of Alabama it may be asserted that the coöperation of

the U. S. Survey has been very distinctly advantageous. In retrospect one can, however, easily see how these benefits might have been materially increased by more frequent conferences and consequently more thorough mutual understandings and adjustments.

Paleontology and Natural History.—With the small amount appropriated for the survey it would have been injudicious to use any of it on paleontology, but Mr. T. H. Aldrich contributed, without cost to the state, Bulletin No. 1, published in 1886, containing descriptions of new Tertiary fossils, with nine plates of illustrations. This is the first installment of what is designed to be a complete and illustrated account of our Tertiary paleontology.

So also Professor Herrick, of Denison University, contributed a List of the Fresh Water and Marine Crustacea of Alabama, with Descriptions of New Species, which was published by the Survey in 1887, as Bulletin No. 1 of Vol. V. This paper, which also appeared as a Memoir of the Denison Scientific Association, is illustrated by eight plates of figures of the species described.

From the beginning of the survey collections have been made by myself of the native plants of the state, and these collections, combined with those of Dr. Charles Mohr, of Mobile, were by him arranged and mounted, and the joint herbarium deposited in the cabinet of the University of Alabama. A preliminary list of the Alabama flora was printed in 1880, and Dr. Mohr is now engaged in preparing for the survey a report on the Botany of the state, in which every known indigenous phænogamous plant and fern will be listed, and full accounts given of the timber, forage, useful and noxious plants. The geographical distribution of the Alabama flora and the mapping of the botanical provinces of the state will be a valuable feature of this report, which is now far advanced towards completion.

In the progress of the work a new species of Croton of shrubby habit, *C. Alabamensis*, has been discovered, and many rare plants have been found growing upon our soil.

Geological Map.—Lastly, the preparation of the geological map of the state has engrossed a large part of the time and

attention of the state geologist for several years. The first difficulty to be overcome was the lack of a suitable base map. In this we had the aid of the U. S. Survey, in which office was compiled the first base map printed by the survey. As the work progressed numerous alterations and corrections became necessary, and not until 1893 was a satisfactory base map prepared. This map, on a scale of ten miles to the inch, with colors to show the geology, will be ready for distribution in a short time. It will be accompanied by a chart exhibiting the main lithological, economic, topographic and agricultural characters of each of the formations represented, and will embody the results obtained during the past twenty-one years.

Cost.—The cost of the survey during this period of eleven years, 1883–1893 inclusive, has been as follows:

Eight annual appropriations of $5,000	$40,000.00
Three annual appropriations of 7,500	22,500.00
Printing, binding, illustrating, and distributing reports . .	13,347.00
	$75,847.00

the entire cost averaging about $6,900 per annum. For the whole period of 21 years during which this survey has been active, the aggregate cost of the survey for all purposes has been $90,597, an average of $4,314 per annum.

Economic results.—Since the organization of the survey, the tax rate has been reduced over 50 per cent., without diminishing the revenues. The increase in the value of property in certain sections of the state that has rendered this possible, has been due in the main to the development of the mineral wealth of the state, and to this the survey publications have contributed a certain share, but how much it would of course be impossible to estimate. In this connection, however, it may be proper to say that some of the regions of the state in which the mining of coal and iron have since assumed vast proportions, were practically untouched by the pick of the miner, when our earlier reports directed attention by maps, analyses, and otherwise to their great resources: and very recently the survey has demonstrated the

existence, within the Coal Measures, of certain areas heretofore untried, in which the mining of coal will undoubtedly be profitable ; it has pointed out a source of wealth in the phosphatic marls of certain sections ; it has shown that gold may be mined with profit at many points within our limits ; it has demonstrated the fact that clays suitable for the manufacture of fine porcelain ware, fire-brick, tiles, and other articles, occur in practically limitless quantity in many sections ; it has pointed out the localities where good marbles and building stones may be had for the quarrying ; all these have as yet not been turned to account.

Unsolved problems.—Of the problems of geological interest, developed in the course of the survey but not yet settled, I may mention the following : The stratigraphic relations of some of our Lower Cambrian formations are still uncertain ; the relations between the formations of unquestioned Cambrian age, and the gold-bearing semi-crystalline strata adjacent to them and in some instances interlocking, are yet to be definitely fixed ; the correlation of the seams of our three coal fields is still an unsolved problem, at least in its details.

Work yet to be done.—After the issue of the publications now in hand, the most important items of work proposed, are 1) The accurate mapping of the outcrops of all the coal seams of economic importance. The finishing of two or three of the sheets of the U. S. topographical survey will render this comparatively easy. 2) The preparation of county maps on the scale of half an inch to the mile, with accurate locations of all mineral deposits, mines, etc., as well as of the geological formations. 3) A republication, or rather a new edition, of the Agricultural report, with a map showing the distribution of the soil varieties. 4) An investigation of the water supply of the Coastal plain region, with special reference to Artesian borings. Much of the material for this is already in hand and in part published.

EUGENE ALLEN SMITH.

THE SUPERFICIAL ALTERATION OF ORE DEPOSITS.[1]

GENERAL FEATURES.

Scope of the subject.—The modern idea of ore deposits teaches that formations of this kind represent a process of concentration of mineral matter, either by chemical or physical means; in other words, that they are unusual localizations of certain minerals which are often found disseminated in smaller quantities in many common rocks, and that they differ from the same minerals situated in other conditions, only in their degree of concentration. These concentrations may take place at different times in the history of the rocks in which the deposits occur. If they occur in sedimentary rocks, they may sometimes be formed during the deposition of the rocks with which they are associated, as in the cases of placer gold, stream tin, and sometimes of other ores;

[1] The superficial alteration of ore deposits is a recognized principle of geology, in the same way as is the superficial alteration of any of the common rocks. Its importance in some classes of ore deposits is also well understood, as in many precious metal deposits; while in other classes, its importance has been proved in individual cases, as in the Lake Superior iron deposits. The causes and effects of superficial alteration in many classes of deposits, however, are not so generally understood, and it is the object of the present paper to show that such changes almost invariably give rise to exceedingly important chemical and physical phenomena, while in many deposits, the question as to whether they can or cannot be profitably worked, depends largely on the extent and character of this alteration.

The various treatises on ore deposits published in the United States and Europe make frequent mention of superficial alteration, but have not treated the subject fully. As early as 1854, however, before which time but little accurate information was had on the geologic nature of ore deposits, Professor J. D. Whitney in his classic volume, The Metallic Wealth of the United States, describes the alteration products, or gossans, in certain deposits and mentions others. On the more purely chemical side of the question, the work of Bischof, Daubrée, Roth, Rose, Hunt, Breithaupt, Blum, Julien, Deville, Debray, Volger, Moissan, Fremy, Lévy, Fouqué and others have afforded much valuable information and many useful suggestions. The chemical principles brought out by these various authors have been applied, to a certain extent, to the solution of the phenomena of the origin of ore deposits, but have not as yet been applied to anything like their possible extent to the solution of the phenomena of the alteration of ore deposits.

while if they occur in igneous rocks, they may sometimes be the result of concentration by differentiation from fused magmas.[1] More usually, however, ore deposits are a result of a concentration after the formation of the enclosing rock, whether the latter be of sedimentary or of igneous origin. The mineral matter represented in this concentration may be derived from the enclosing rocks or closely adjacent rocks, as in the case of many, if not most, iron ore deposits; or it may be derived from more distant sources, often from greater or less depths, as in some of the precious metal deposits. Occasionally, both these sources may be drawn on for mineral matter in one deposit. In this subject of the original source of an ore, we enter a field concerning which there has been much dispute of late years between the advocates of the lateral secretion theory and those who favor the idea of a deep-seated source for many ore deposits. It is not, however, the purpose of the present paper to enter into this discussion, and the following remarks are confined to what happens in the superficial parts of ore deposits, and to a less extent of allied formations, after the materials forming them have been brought into their present, or approximately their present, positions.

Relation of alteration in ore deposits and in country rocks.—Ore deposits are generally more or less changed in their upper parts by atmospheric influences, so that very rarely do the same mineralogical and physical features that are found in these parts, continue to very great depths. In considering this superficial alteration, we discuss a subject analogous to the secular decay of rocks. The latter, however, involves usually but a limited number of common rock-forming minerals, while the secular decay of ore deposits involves a great variety of minerals, not only the oxides, carbonates and silicates common in most rocks, but also sulphides, arsenides, tellurides, selenides, antimonides, chlorides, bromides, iodides, fluorides, sulphates, phosphates, tungstates, molybdates, and numerous other classes of minerals, many of

[1] This has been shown by J. H. L. Vogt (Zeitschrift für praktische Geologie, January, 1893) to be true of certain titaniferous iron ores and other deposits in the eruptive rocks of Norway. It may also be true of certain titaniferous iron ores in the United States.

which, under surface influences, give rise to intricate chemical changes. In discussing the subject of the superficial alteration of ore deposits, therefore, we treat a similar, but much less understood, subject than the superficial alteration of rocks.

Technical names of alteration products.—The altered surface outcrop of ore deposits is known by various names in different regions. Among the Cornish miners of England it is known as gossan, a name which has also been adopted into American mining nomenclature, though other special names are given in special classes of deposits. In France it is known as chapeau de fer; in Germany as eisener hut; among the Spanish Americans as pacos or colorados. As almost all deposits contain more or less iron minerals, the outcrops are usually stained brown from their oxidation, and hence the reference to iron in the French and German names. Sometimes, however, the outcrops are stained black by the oxidation of manganese carbonate or silicate, or green by copper minerals, or other colors by the formation of other compounds.

Agents of alteration.—The superficial alteration of ore deposits, as of any rock, results from a combination of mechanical and chemical disintegration, brought about by the combined action of the atmosphere, surface waters, changes in temperature, and the various organic and inorganic materials contained in the air and water. In nature, we never deal with perfectly pure water, but different waters contain different ingredients derived from the air and from the different materials with which they come in contact. Among the most important of these ingredients are oxygen, numerous organic acids like carbonic, oxalic, malic, citric, formic, propionic, butyric, acetic acids, etc., certain inorganic acids, such as sulphuric, nitric, hydrochloric, hydrobromic, etc., etc. Some of the acids mentioned occasionally occur in the free state, but most of them are generally combined with some of the bases present, such as the alkalies, lime, magnesia, iron, alumina, etc. These various ingredients, of course, are not all contained in the same waters, but are found in various associations in different waters. The organic acids mentioned represent

various stages of oxidation of materials from organic matter, but they all eventually, if allowed to become completely oxidized, pass into carbonic acid; while if they are in combination with different bases, these salts are eventually converted to carbonates.

Method and chemical effects of alteration.—Surface waters thus charged with various chemical ingredients percolate down into ore deposits, and there meet various materials which are even less stable under their influence than most of the common rocks. The alteration, therefore, is comparatively rapid, and, though only superficial, generally extends to much greater depths than in the surrounding country rock. From a chemical standpoint, the first effect of this superficial influence is usually the oxidation or hydration, or both, of certain ingredients, followed generally by the formation of other chemical combinations and by the leaching of certain materials. In the formation of these other chemical combinations, however, the base usually remains the same, and the alteration consists generally in a change of the materials associated with the base, that is, in the acidic portion of the mineral or the part that represents the acidic portion. Thus, iron sulphides are oxidized to iron sulphate, and then this is converted by further oxidation and by hydration to the hydrous sesquioxide. Copper sulphides may be oxidized to copper sulphate ; and from the sulphate, by the agency of materials in surface waters, may be formed copper carbonates, haloid compounds, silicates, oxides, and even metallic copper ; while from some of these, still other compounds may be produced. Similar reactions occur in many lead, zinc, silver, gold, and other deposits.

Occasionally, chemical changes may occur without previous oxidation, and sometimes, though rarely, surface influences under peculiar conditions may have a reducing effect, as in the formation of iron pyrites and copper pyrites from the sulphates of iron and copper, or in the formation of native copper by the action of a ferrous salt on certain copper salts, or in the formation of native silver in surface outcrops. In many of such cases, however, the chemical action is primarily one of partial oxida-

tion, and the reducing action follows as the effect of one of the partially oxidized compounds on the other, as in the case of copper just mentioned. In deposits, such as gypsum, a reduction, due sometimes to superficial influences, is seen in the occasional formation of sulphur from gypsum.

An important chemical effect of surface influences is the removal in solution of certain ingredients of the ore deposit which are soluble in surface waters ; as the removal of the calcite gangue of many silver and other deposits ; the oxidation and removal of the sulphur in various silver, lead, zinc, copper, and other deposits ; the oxidation and removal of both the iron and sulphur of iron pyrites in auriferous quartz veins ; the removal of silica from certain iron deposits, such as those in the Lake Superior region, etc. Probably many phosphate deposits are formed by the superficial leaching of carbonate of lime from calcareous beds, and the corresponding concentration of phosphate of lime once finely disseminated in the same beds.

Another chemical effect of superficial alteration is seen in the occasional formation of mineral deposits of importance by certain materials carried from outside sources and deposited in a rock of otherwise no commercial value. Thus certain phosphate deposits of the South Pacific Ocean, the West Indies and possibly of Florida, are formed by the leaching of soluble phosphates from guano, their transportation down into underlying limestone or coral reefs, and the precipitation of the phosphoric acid as tribasic phosphate of lime, which, being almost insoluble, arrests further escape of the phosphatic materials.

Again, another chemical effect is seen in the incrustations, and even extensive beds, of saline materials, like borax, nitre and the various alkaline salts of the western arid regions, formed by precipitation from water rising by capillary action through the soil, becoming evaporated on the surface and depositing the saline materials which they have dissolved from below. Many saline deposits are formed by the simple evaporation of surface waters, such as lakes, seas, etc., but certain deposits undergo only an initial concentration in this way, and are laid down with

clay, sand, and gravel, while further concentration is due to this capillary action. In the case of nitre, indeed, the saline material is very often, if not generally, formed in soils or guano beds and undergoes its first concentration by this capillary action.

In the various chemical changes mentioned above, the class of salts that remains, whether oxides, carbonates, haloid compounds, etc., varies with the nature of the bases affected. Thus, iron sulphides and copper sulphides are both oxidized and form sulphates. But here the similarity of their behavior ends, for the iron sulphate probably passes then into a basic sulphate and then into a hydrous sesquioxide, while the copper sulphate takes up carbonic dioxide and water and forms basic carbonates. The iron sulphate might, under certain conditions, form a carbonate in a similar manner, but this compound would be very unstable under the conditions existing in the alteration of sulphide deposits and would quickly go into the form of the hydrous sesquioxide, while the carbonate of copper is stable under existing conditions and remains.

In the same way, if silver sulphide and iron sulphide are both oxidized and then affected by waters carrying common salt or other chlorides in solution, the silver is converted to chloride, which is insoluble and remains; while the chlorides of iron are much less liable to be formed, as they are soluble, and some of them unstable, compounds, and even if they were formed, they would be leached out or oxidized. Hence, though chloride of silver is a common product of alteration in silver deposits, chloride of iron is never found, at least to any extent, as a product of alteration of iron deposits.

Again, it is frequently found that unaltered auriferous iron pyrites contains a certain amount of silver, while the altered part often carries almost none. In such cases, the gold has remained stable during the alteration, while the silver, in the absence of a chloride or other reagents to convert it to an insoluble compound, has been dissolved and carried away in solution by the acid materials generated during alteration.

Hence, the materials in surface waters affect different bases

differently, and, therefore, there is a great difference in the classes of salts formed by the same surface waters on the ores of different metals. In the same deposit there may be formed an oxide of one metal, a carbonate of another, a chloride of another, etc. In fact, in some of the silver deposits of southern New Mexico, there can be found hydrous sesquioxide of iron formed from iron sulphide, carbonates of copper formed from copper sulphides, and chloride of silver formed probably from silver sulphides, and yet in all probability the same surface waters produced all these changes practically simultaneously.

As a result of these various changes, certain materials are sometimes leached from the upper parts of ore deposits, which have become porous by alteration, and carried down to the less pervious unaltered parts. Here they are precipitated by meeting other solutions or in other ways, and hence the richest bodies of ore in a deposit often occur between the overlying altered part and the underlying unaltered part. This is not always the case, but it is true of some copper, silver, iron and other deposits.

Physical effects of alteration.—From a physical standpoint, the effect of superficial alteration is generally to make the deposit more open and porous, to cause it to shrink, and, in some cases, to convert it to a loose material of the consistency of sand and clay. In some cases, however, especially where considerable hydration goes on, an expansion may be caused. This is well seen in the formation of gypsum by the hydration of anhydrite, often causing an expansion sufficient to brecciate and fold the associated rocks,[1] and amounting to about 33 per cent. of the original material.[2] In the conversion of carbonate of iron to the hydrous sesquioxide of iron, or limonite, it has been found[3] that there is a contraction of 19.5 per cent., giving the deposit the loose porous structure characteristic of limonite and forming the familiar

[1]Elie de Beaumont, Explic. Carte géol. de France, Vol. II., p. 89. R. A. F. Penrose, Jr., Arkansas Geol. Survey, 1890, Vol. I, pp. 535-538.

[2] A. Geikie, Text Book of Geology, 3d Edition, p. 345.

[3] T. Sterry Hunt, Mineral Physiology and Physiography, 1889, p. 262.

limonite geodes.[1] In this case carbon dioxide has been removed from the iron, but oxygen and water have been added. A porosity is also produced by the removal of certain ingredients in an ore deposit without the addition of others, as in the oxidation and leaching of iron pyrites in veins of auriferous quartz, leaving a loose, porous, spongy quartz mass.

Surface decomposition has also, in many places, not only affected the ore deposit itself, but also the country rock in the immediate vicinity, and has converted it into a loose material of a sandy or clayey consistency, as at Iron Mountain, Missouri, in the Batesville manganese region of Arkansas and in other localities described beyond. In the iron and manganese deposits of the Cambrian and Lower Silurian rocks in the Appalachian region, the limestones and shales, which once enclosed the ore bodies, have often been converted to clay in the same way as in the Batesville region; and, in fact, the common mode of occurrence of these deposits is as residual clays carrying irregular bodies and nodules of ore.

This decay of the country rock in immediate association with ore deposits, is generally more extensive than in similar rocks not associated with such deposits, and, therefore, requires further explanation than the simple action of ordinary surface waters. The explanation is, doubtless, in many cases, that the rock has decayed under the influence of the same waters that originally concentrated the ore; and as these waters differed from most waters in character and in the materials they held in solution, they often had an abnormal effect. Moreover, when subsequently the ore body is affected by surface influences, sulphuric acid is liberated from sulphides and carbonic acid from carbonates, as well as other acids from other minerals, and all these materials have an active effect on most rocks. Moreover, the porous nature of many ore deposits, after they have been altered on the surface, allows a freer percolation of surface waters than elsewhere in the same country rock, and, hence, a correspondingly greater decay.

[1] R. A. F. Penrose, Jr., The Tertiary Iron Ores of Arkansas and Texas, Bulletin Geological Society of America, Vol. 3, 1891, pp. 44-50.

Another physical effect of surface influences on ore deposits is seen in certain forms of brecciation due to physical or chemical causes, such as expansion by hydration, etc. Such brecciation, however, has usually occurred in the country rock before the concentration of the ore deposit; in fact its existence, by offering favorable conditions for deposition, has often been the cause of the formation of the ore deposit in a given place. Though brecciation, therefore, is very important as a factor in the concentration of ore deposits, it does not belong, to any large extent, in a discussion of the surface alteration of ore deposits after their formation, and, therefore, it will not be treated further in this paper.

Depth of alteration.—Having thus discussed briefly the means by which superficial alteration in ore deposits is produced, and the results of this alteration, the next feature to be taken up is the depth to which it extends. As already shown, the alteration is primarily one of oxidation and generally of hydration; and, though either may occur without the other, they both very often occur together. When surface waters percolate into the rock, their influence is more active near the surface, because they carry large quantities of oxygen, and because the oxygen of the air itself also has some influence. As they sink deeper, the effect of the oxygen of the air becomes less active, and the oxygen dissolved in the water is consumed in oxidizing various materials which it meets on the way, until finally most of the oxygen is lost and active oxidation ceases. Theoretically, this oxidizing action may extend down as far as, and sometimes below, the level of the drainage of the surrounding country, which is called also the zone of permanent saturation. Above that level, there is a constant circulation of water from the surface downwards, thus affording means of active oxidation; but when the water reaches that level, not only has most of the oxygen contained in solution generally been used up, but also the circulation of the water is much more sluggish, so that oxidation is less active.[1]

[1] It is possible that the oxidation near the surface is due largely to free oxygen in the waters, while, when this becomes exhausted at a depth, the oxidation may be due to the abstraction by mineral matter of the oxygen in combination with materials in solution.

The process of hydration, when the materials affected do not require oxidation before they can become hydrated, may extend down indefinitely below the limit of oxidation; but when oxidation is necessary before hydration is possible, the latter process of course can extend no deeper than oxidation. Thus the silicate of alumina in feldspar may become hydrated and form kaolin without the intervention of oxygen. This is brought about by the action of carbonic acid and water, which react on the feldspar and form alkaline carbonates, kaolin and free or hydrous silica. Theoretically, therefore, kaolinization ought to go on to any depth that can be reached by water and its almost universal accompaniment, carbonic acid. In this case, however, the base in question is already in its peroxide condition ($Al_2 O_3$), but when a base is not in this condition, it frequently requires oxidation previous to hydration. Thus sulphide of iron does not become hydrated until it is peroxidized, and this mineral, therefore, requires oxidation previous to hydration.[1]

The various materials other than oxygen in surface waters have a very important effect on the mineral matter with which they come in contact, and their action sometimes takes place before that of oxidation, though it often requires at least a partial previous oxidation. The effect is both to form new chemical compounds with the materials involved, and to dissolve and bodily remove certain materials. As with oxygen, however, so with these other agents of alteration, they are more active above the drainage level of the country than below it, and an additional reason for this is that many of the materials affected require a primary oxidation before they enter into other chemical combinations. Thus sulphide of lead is oxidized to sulphate of lead before it can take up carbonic acid and form carbonate of lead; while on the other hand, carbonate of lime can be converted to sulphate of lime (gypsum) by the action of sulphuric acid or certain sulphates without any change in the degree of oxidation of the lime.

[1] For a full discussion of this subject see H. Rose, Ueber den Einfluss des Wassers bei chemischen Zersetzungen, Pogg. Ann. der Physik und Chemic, 82 et seq.

It will thus be seen that in going from the surface downwards, we pass from a zone of active oxidation into a zone in which oxidation practically ceases. Below the level of permanent saturation, the waters may sometimes gradually sink to very great depths, even deep enough to become intensely heated and possibly dissociated. Such water may have a very important effect in the formation of ore bodies, though in a manner quite different from their action on the surface. The present discussion, however, relates not to this, but to only superficial influences.

Though theoretically, therefore, alteration of one kind or another may extend down to, and in some cases much below the level of permanent saturation, and if given sufficient time would actually go to such depths; yet in many, if not most, cases it has not yet reached that level. The actual depth to which alteration does extend varies with the topographic conditions of the region, the chemical nature and the porosity of the deposits affected, the character of the climate, and other minor conditions.

The topography of a region affects the depth of alteration, because it is one of the principal features in determining the depth of permanent saturation. The chemical nature of the deposit affects the depth of alteration because on this depends the degree of resistance it will offer to the chemical effects of percolating waters. The porosity of the deposit affects the depth of alteration because, in deposits of similar kind but of different porosity, the more porous will be more accessible to surface influences, and will, therefore, be more affected, in a given time, than the less porous deposit.

The climatic conditions, such as the amount and manner of occurrence of rainfall and other forms of atmospheric moisture, and the rate and degree of variation in temperature have a large influence on superficial alteration. On the amount of rainfall and other forms of atmospheric moisture depends the amount of moisture available as an agent of alteration ; while on their mode of precipitation depends, other things being equal, the amount of water which would sink into the deposit, thus effecting alteration,

and the amount that would immediately run off the surface or be evaporated and thus have but little altering effect. The rate and degree of variation in temperature affect the amount of breaking in the rock by expansion and contraction, and, therefore, the accessibility of the rock to surface influences. The character of the climate also influences, to a certain extent, the nature and amount of vegetation, and from the vegetation are obtained many organic acids which assist the action of surface waters. In other ways, also, such as in the generation of nitric acid in the atmosphere, the character of the climate influences the agents of alteration.

As a result of all these influences, surface alteration is found to extend in different ore deposits to depths varying from only a few inches, or in fact only a fraction of an inch, to several hundred and even a thousand or more feet. In glaciated regions the products of decay have often been swept away by glacial action, and the time which has elapsed since then has not been sufficient for alteration to have extended to any great depths; while in regions of moist climates, the erosion sometimes, though not always, keeps pace with the alteration, so that the depth of the change is shallow. In those regions, however, which have not been recently glaciated and which have dry or only moderately moist climates, so that erosion is slight, or in places which have moist climates, but which, on account of their topography, are not subjected to very active erosion, the products of alteration collect, and the changes are traceable downwards often to great depths.

In the copper regions of Michigan, the deposits have been exposed to glaciation, and are still exposed to the active effects of erosion in a moist climate, so that here, though the native copper of the region is a material very easily affected by surface alteration, yet the only change observable is a slight stain of copper carbonate or oxide on the surface of some of the native copper, and even this is not always present. On the other hand, in the arid region of the west, most of which has not been recently glaciated and which has an exceedingly dry climate, the

residual products of alteration have accumulated to great thicknesses. This region, however, had once a much more moist climate than now, and some of the alteration may have occurred then. Many of the Arizona copper deposits in this region originally contained their copper in the form of copper pyrites, which, under similar conditions, is probably more resistant to surface alteration than the native copper of Michigan, and yet it has been changed to various other copper minerals for depths often reaching from 100 to over 700 feet. In Chile some of the copper sulphide deposits are said to have been altered to a depth of 1,500 feet, but it is very rare that much alteration extends in any ore deposits to greater depths than this. In the more moist climate of Tasmania, the results of alteration are also very marked.

The depth of alteration of ore deposits in unglaciated regions in the United States varies from a few feet to over 1,000 feet. In the Appalachian region, many of the deposits of auriferous quartz, iron pyrites, copper pyrites, etc., are altered to depths varying from less than one to a hundred feet or more. Many of the Clinton iron ore deposits are altered to still greater depths. The depth of alteration in these Appalachian deposits is usually much greater, other things being equal, south of the limit of glaciation than north of it. In the silver, lead, gold, and copper deposits of the Rocky Mountains and the western arid region, such as at Butte City, Leadville, Central City, Cripple Creek, Silver City, Lake Valley, Eureka, Virginia City, Park City, the Coeur d'Alene district, and elsewhere, the alteration has reached depths ranging from 50 to 600 or 700 feet, and in some rare cases still more. At Granite Mountain in Montana, signs of alteration are seen in the argentiferous quartz deposits of that region, even at depths of 900 feet, though of course at such depths the alteration is slight as compared with that nearer the surface.

Complete alteration rarely extends to these greater depths, and usually parts of a deposit which have as yet escaped alteration appear comparatively near the surface. These are at first very few and may be entirely enclosed by altered products, but with

increased depth they become more numerous and continuous, until they predominate over the altered products, and finally, when the limit of alteration is reached, they entirely replace them. The planes of contact between an ore deposit and the country rock, that is the walls, afford, when well defined, easy passages for the downward percolation of surface waters, and therefore alteration frequently continues down along these lines for considerable distances after the limit of alteration in the main part of a deposit has been reached. Any other possible channels, such as the planes of contact of different minerals in banded deposits or the series of drusy cavities often found in the central parts of ore deposits, may act in the same way as passages for water. Hence the not infrequent abundance of alteration products, such as hydrous sesquioxide of iron, and native copper and silver, along the walls and elsewhere in certain deposits.

Classification of the products of alteration.—The products of superficial alteration may be divided into two general classes: (1) Those which occupy the same position as the materials from which they were derived, or are only slightly removed, and possess the same general environment. Thus the altered outcrops of auriferous quartz and iron pyrites, of argentiferous galena, of sulphides of copper and many other similar deposits, represent alteration-products occupying the same general position as the original sulphide ores; while the iron ore bodies of the Lake Superior region represent alteration-products changed somewhat in position from that occupied originally, but yet in the same series of rocks and sometimes with somewhat similar environment. (2) In the second class are included those deposits which have been entirely removed from their original position and redeposited under totally different environments. Thus, placer gold deposits, stream tin, most of the deposits carrying platinum and the allied metals, magnetic and chromite sand, the gravels and sands carrying precious stones, and many other similar deposits represent this class. They have been derived by the decay and erosion of veins, dikes or country rocks carrying the materials now concentrated in these fragmental deposits.

The materials in their original environment may or may not have been sufficiently concentrated to serve as commercial sources of supply, but the fragmental deposits mentioned almost always represent a further concentration. This class of deposits is of great importance, but the present discussion relates more especially to the superficial alteration of deposits that remain *in situ*, and therefore these will be treated more in detail than the other class, (No. 2), though the latter will be mentioned as occasion requires.

SUPERFICIAL ALTERATION IN DIFFERENT DEPOSITS.

Alteration in iron deposits.—It was once generally believed that most iron deposits were the result of direct precipitation from aqueous solution, or in rarer cases, were igneous masses. It has long since been shown, however, that most workable iron deposits are the result of a concentration subsequent to their deposition, while very few are due to a direct precipitation during the formation of sedimentary rocks, though some may be due to a process of differentiation in the cooling of eruptive magmas.[1] The original presence of the iron in sedimentary rocks was doubtless due to a direct precipitation during the formation of the enclosing rock, but it was then in a finely disseminated condition, and it was only by being subsequently taken into solution again by percolating waters and concentrated, that it was converted into bodies of greater or less purity. Generally, though possibly not always, this process is superficial, and though it may extend to a depth of several hundred or even a thousand feet or more, it can be traced directly to surface influences, and its effects are seen to decrease gradually with depth. Shaler,[2] in 1877, showed that some of the limonites of Kentucky, Ohio and elsewhere were concentrations of iron derived in solution from shales and other rocks and reprecipitated in underlying limestone.

[1] See foot note on second page of present article.

[2] N. S. Shaler, Kentucky Geol. Survey, Report of Progress, Vol. III., New Series, 1877, p. 164.

Van Hise,[1] in 1889, showed that the iron deposits of the Lake Superior region are concentrations of iron formerly disseminated in a siliceous rock containing carbonate of iron and other carbonates, and called by him cherty iron carbonate. This disseminated iron was taken into solution by surface waters, carried down until its passage was obstructed or impeded by less pervious rocks, often dikes, and there precipitated by meeting with other solutions of a different nature. These other solutions contained oxygen, while the iron-bearing solutions had been largely robbed of their oxygen and had been freed from silica by the large amount of carbonic acid they contained. When, therefore, the two solutions met, the iron in solution was oxidized and precipitated ; while the silica, in the spot where this precipitation occurred, was, on account of the dilution of the carbonated waters with the other waters, and through the agency of alkaline carbonates, dissolved and carried off, thus gradually increasing the amount of iron and removing the silica. By this theory, the iron is largely a replacement of the silica of the cherty iron carbonates, and has been derived from the parts of the strata exposed to superficial influences. The deposits are, therefore, of only superficial extent, though they may reach over 1,000 feet below the surface, yet when they pass below the action of surface influences, the iron has not been concentrated and they are of too low grade to be mined for iron ore. The methods of local concentration proposed by Professor Van Hise for these Lake Superior iron deposits, are equally applicable to certain other iron deposits, and are a most valuable addition to our knowledge of chemical geology. They also bring out in a most prominent manner, the fact that even rocks composed of materials like silica, which are very resistant to surface influences, may, under proper conditions, be replaced on a large scale.

[1] C. R. VAN HISE, The Iron Ores of the Penokee-Gogebic Series in Michigan and Wisconsin, Amer. Jour. Sci., 3d series, Vol. 37, 1889, pp. 32-47 ; The Iron Ores of the Lake Superior Region, Trans. Wisconsin Acad. Sci., Vol. VIII., 1891. For a fuller discussion by Van Hise on this subject see United States Geol. Survey, Tenth Annual Report, 1888-89, Pt. I., pp. 409-422 ; Monog. U. S. Geol. Survey, No. XIX., 1892.

The iron deposits of the Mesabi Range in Minnesota, which have lately been described by H. V. Winchell[1] are supposed to have had a somewhat similar origin to that given for the Michigan and Wisconsin ores by Van Hise. Winchell believes that they are due to the concentration by surface agencies of iron disseminated as oxides in a highly siliceous rock, and that in this concentration the silica has been replaced by iron.

The red hematites of the Clinton horizon of the Upper Silurian in the Appalachian region have been at least partly formed by superficial concentration which extends to only limited depths.

The iron deposits in other geologic horizons of the Appalachian valley, especially in the Cambrian, Lower Silurian and Carboniferous rocks, are also often much changed by the action of surface influences. Many of the deposits in the Cambrian and Lower Silurian can be clearly shown to be due to a superficial replacement of limestone, or even of more siliceous rocks like shales, by iron dissolved from ferruginous rocks in the neighborhood. In such cases, the iron in the original rock has been dissolved and carried off in carbonated surface water, and re-precipitated in the other rocks, all these stages being directly due to surface influences. Many of the carbonate iron ores of the Carboniferous rocks are rendered not only of higher grade, but also more easy to treat, by the oxidation of the carbonate to the sesquioxide and the removal of the carbonic acid. Moreover, these carbonate ores often occur as nodules, "kidney ores," in shale, and, on the surface, this shale has been softened by atmospheric conditions, thus facilitating mining; while away from the surface, the shale becomes harder and makes mining more expensive.

Surface influences on carbonate of iron have been made use of artificially in Styria, where a very hard spathic iron ore has been mined and spread out on a hill side for from 20 to 25 years. By this process the ore was oxidized and made more porous, and thus became very much more cheaply treated.[2]

[1] Minnesota Geological Survey, Twentieth Annual Report, pp. 136-148.

[2] Letter from MR. CHARLES E. SMITH, Philadelphia, Pennsylvania.

At the celebrated Iron Mountain in Missouri, a large part of the ore came from conglomerates composed largely of fragments of iron ore, which had been weathered out of the pre-Cambrian rocks that had originally contained them. These conglomerates lie at the base of the Cambrian strata which overlie the pre-Cambrian rocks, and even in the latter rocks, where exposed, the original ore has been made much more easy to work by the decay of the enclosing material and its conversion to clay.

In the iron region of eastern Texas, the limonite ores are often a result of the solution of iron from the superficial oxidation of iron pyrites, iron carbonate and glauconite. Sometimes the sequel of this process is the downward passage of the solution to an underlying laminated clay, and the gradual replacement of this bed, forming a hard limonite,[1] which still preserves the laminated structure of the clay.

In Mexico certain hematite deposits described by R. T. Hill[2] as occurring in Lower Cretaceous limestone at or near the contact with intrusive masses of diorite, and sometimes even in the diorite itself, may, as Hill suggests, be the result of superficial concentration from the limestone.

Very large deposits of hematite also occur in Grant county, New Mexico, at the contact of limestone and an eruptive. The origin of this ore is as yet somewhat obscure, but is probably due to a concentration after the original deposition of the iron.

The iron deposits in the lakes of Sweden and Norway are most striking instances of a concentration of iron ore due to surface influences and going on at the present time. The iron is derived from the oxidation of the neighboring rocks, carried by carbonated surface waters to the lakes, and there, by further oxidation and hydration, precipitated as hydrous sesquioxide (limonite). The iron ore is dredged up and used, but the processes of nature gradually replace it, and, in the course of years, the lakes again accumulate a considerable thickness of ore.

[1] R. A. F. Penrose, Jr., Geological Survey of Texas, First Annual Report, 1890, pp. 72–76, 79–81; also Bulletin Geological Society America, 1892, pp. 47–50.

[2] Amer. Jour. Sci., Vol. XLV., 1893, pp. 111–120.

Many other similar cases of superficial enrichment in iron deposits might be mentioned, but the above are enough to illustrate the point in question, and it will be seen that, of the regions which are the active producers of iron ore in this country, almost all, if not all, owe the existence, or at least the availability of their large bodies of ore, to superficial concentration.

Alteration in manganese deposits. — Manganese deposits are affected by superficial influences in much the same way as iron deposits. Many of the manganese deposits in the Cambrian and Lower Silurian rocks of the Appalachian Valley were concentrated in a manner somewhat similar, though not always so, to the iron deposits in the same regions.[1]

In the Batesville manganese region of Arkansas, the ore originally occurred in irregular masses in Silurian limestone, but surface decay has leached the carbonate of lime out of the limestone, leaving a red siliceous clay, which represents the less soluble part of the original rock. This clay now lies in hollows on the surface of the limestone and contains the masses of ore once disseminated through that rock. The removal of the carbonate of lime has concentrated the ore masses in the clay, and has also rendered them more easily mined ; in fact, the only manganese ore that can now be profitably mined in this region is that in the residual clay.[2]

The frequent occurrence of deposits of bog manganese ore in the areas of crystalline rocks, generally represents a concentration of manganese resulting from the oxidation of disseminated carbonate and silicate of manganese in the country rock. This oxidation product is taken into solution in surface waters, and transported until subjected to such conditions that it is oxidized and precipitated as a hydrous oxide.

Alteration in copper deposits.—In many copper deposits superficial alteration has produced very remarkable chemical and economic results, and this is especially well seen in the copper

[1] R. A. F. PENROSE, JR., Journal of Geology, No. 4, Vol. I., 1893, pp. 356–370.

[2] R. A. F. PENROSE, JR., Manganese : Its Uses, Ores, and Deposits ; Arkansas Geological Survey, 1890, Vol. I., pp. 166–209.

sulphide deposits of Arizona, Chile and elsewhere. In Arizona the upper parts of the deposits are composed of brown or black ferruginous masses, with brilliantly colored oxidized copper minerals, as cuprite, malachite, azurite, chrysocolla, etc.; while below, at depths varying from a few feet to several hundred feet, the deposits usually pass into a mixture of copper pyrites and iron pyrites, the latter usually being far in excess. Sometimes other copper sulphides occur, either mixed with copper pyrites or free from it, and they may or may not have been derived from it. Here the carbonates and some of the other alteration minerals contain not only more copper than the unaltered copper pyrites, but they are also in a much more concentrated condition than the sulphide which is disseminated through iron pyrites. The total amount of copper has not been increased, in fact it may be decreased by leaching, but it is in a more concentrated form, and therefore the ore obtained from these concentrations averages from eight to thirty per cent. or more in copper, while the mixture of unoxidized copper pyrites and iron pyrites below averages only about five per cent. in copper. Moreover, the altered ores are much more cheaply treated than the unaltered ones, and are therefore still more desirable. It will thus be seen that the economic value of the deposits as a whole has been greatly increased.

In the surface alteration of these deposits, the copper sulphides have first been converted to copper sulphate and then, by the action of surface waters and the materials contained in solution in them, they pass into the forms of copper carbonates, oxides, silicates, and occasionally to the chlorides and bromides, and sometimes to native copper. The iron sulphide is first converted to sulphate and then this, through other stages, is converted into the hydrous sesquioxide (limonite), though the iron sometimes now occurs in the form of the anhydrous sesquioxide (hematite). This may have been derived from the limonite by dehydration, or, under certain conditions, may have been formed directly by the oxidation of iron pyrites. The oxidized copper minerals in the upper part of

the ore deposit have been concentrated partly by segregation during alteration, and partly by the leaching of the associated materials. As a result of this, these minerals occur as seams, pockets or irregular bodies, often a hundred feet or more in diameter, generally enclosed by, and often intimately associated with, the oxidized iron materials which represent the gangue.

In the case of the Arizona deposits, alteration has progressed just far enough to increase greatly the value of the deposits without to any extent injuring it. Such products of alteration, however, are more or less soluble in surface waters containing various organic and inorganic compounds, so that in a moist climate there is a constant tendency to leach them out and leave only the less soluble parts of the gangue. In Arizona, this stage has not yet progressed to a noticeable degree, and one reason for this may be the extreme dryness of the climate, which affords opportunity for only comparatively slight percolation of surface waters.

In the copper deposits of Montana and the Appalachian region, however, a further stage of alteration is often observable. The copper deposits at Butte City, Montana, are composed largely of chalcocite, with copper pyrites, bornite, enargite, iron pyrites and other minerals in a siliceous gangue. On the surface the copper in these deposits has been almost entirely oxidized and leached out, and the ore consists of a porous, rusty, siliceous mass which was once mined for the small percentage of silver it contained. As depths were reached, the oxidized copper minerals began to appear, and eventually the sulphides formed the mass of the veins. In this case, a further stage of alteration is seen than that in Arizona.

At Ducktown in eastern Tennessee,[1] deposits of mixed iron and copper pyrites occur and have been altered in a somewhat similar manner on the surface. The copper minerals have been leached out of the ferruginous gangue in the upper parts of the deposits, and for a depth of from 20 to 80 feet or more, the deposits are composed simply of a porous mass of more or less

[1] J. D. WHITNEY, The Metallic Wealth of the United States, pp. 322–324.

hydrous sesquioxide of iron. Below this a part of the copper, which has been leached from above, has been carried down and deposited as a dark material, probably composed largely of oxides and sulphides of copper, and averaging sometimes 20 to 25 per cent. or more in metallic copper. This material immediately overlies the unoxidized mixture of copper and iron pyrites, which averages only from 2 per cent. to 4 or 5 per cent. in copper. The commercial copper mined in this region came from the part of the deposit below the iron capping and above the unoxidized sulphides. When this was exhausted, the mines had to be closed, for the unaltered sulphides were too poor to be utilized.

In Chile, Peru, and elsewhere in South America, changes in copper deposits, somewhat similar to those described in the United States, frequently occur. In fact, the great reputation which Chile once had as a copper producer, was largely due to this surface alteration, for the oxidized ore once supplied a rich and easily treated source of copper, but when the mines reached the unoxidized sulphides, the ores became poor in copper and more difficult to treat, so that the copper industry of Chile began to decline. In that region, however, the oxidation has in some places extended down as far as 1,500 feet.

Alteration in lead deposits.—In the case of lead deposits, the mineral galena, which is the commonest ore, is frequently more or less altered on its surface outcrops and converted to the sulphate (anglesite) and the carbonate (cerussite). The first product of oxidation is anglesite, but this is a soluble compound and readily unites with carbonic acid or soluble carbonates in surface waters, forming the carbonate of lead, or cerussite. In rarer cases, other lead minerals, like phosphates, may also be formed.

Alteration in silver deposits.—Galena deposits often contain silver, possibly sometimes in the same condition of sulphide as the galena, and this material is altered at the same time as the lead, with the formation of native silver, chloride of silver (cerargyrite), bromide of silver (bromyrite), iodide of silver (iodyrite),

and various other minerals. The native silver is formed, probably, only after a preceding oxidation of the sulphide. Deposits carrying other unaltered silver-bearing minerals, such as the various silver sulphides, arsenides, antimonides, tellurides, etc., are, when exposed to surface influences, affected in much the same way as the silver in argentiferous galena.

Alteration of zinc deposits —In the case of zinc, the most common ore is the sulphide known as blende. This mineral, like galena, is generally oxidized on the surface, and forms by other chemical changes the carbonate (smithsonite), the basic carbonate (hydrozincite), and the basic silicate (calamine), in a manner similar to that described in copper and lead ores.

In the cases of both lead and zinc, oxidized ores are very desirable for metallurgical purposes, and are much sought after. To be sure, the carbonates, sulphates, etc., of lead and zinc contain less of these metals than the pure sulphides, but they occur in a more concentrated form than the sulphides, and, therefore, the ores containing them frequently carry as much or more of the metals than the ores containing the sulphides. Moreover, the oxidized ores are much more easy to treat and, therefore, have an additional value over the sulphide ores.

Alteration in gold deposits.—In the case of gold deposits, surface alteration has a most marked effect, and probably in no class of deposits is the change of more geologic and economic importance. The typical unaltered condition of gold in nature is in association with iron pyrites in quartz, the gold being sometimes in such association with the pyrites that it cannot be separated by mechanical means, while in rarer cases, it can be so separated. The effect of surface oxidation on such a deposit, is first to convert the iron pyrites into a hydrated sesquioxide of iron, which premeates the white quartz, with which the pyrites is usually associated, and turns it into a rusty brown mass. The next stage is the gradual leaching out of the hydrous sesquioxide by the action of surface waters. The iron is, in this way, finally removed altogether, and the remaining product is a pure white quartz, containing the gold which was originally in the

iron pyrites, and which has remained stable during the oxidation and leaching of that mineral. Such quartz is usually porous and spongy, and is filled with cavities which represent the shapes of the original crystals of iron pyrites, and which, during an intermediate stage, have been partly filled with hydrous sesquioxide. This leaching, however, is rarely complete, and the quartz is usually stained brown on the surface.

In gold deposits of this kind, other minerals, such as copper pyrites, galena, blende, etc., frequently occur, and when the deposit is affected by surface influences, these minerals act in the manner already described under copper, lead, and zinc. It is not uncommon to see gold-bearing quartz stained green by oxidized copper minerals, or black by manganese minerals. Sometimes, especially in the Rocky Mountain region, gold occurs in the form of a telluride instead of in iron sulphide, and in such cases, the telluride is oxidized and the gold set free from its combined state. The gold, in being freed from pyrites or other minerals, is not only concentrated by the removal of certain ingredients of the deposits, but it is brought into a condition in which it is much easier to treat than the unaltered part of the deposit, and, therefore, the upper parts of most gold-bearing veins are greatly enhanced in value. The ore from these parts is known as "free milling" ore, because it can generally be ground and the gold extracted by direct amalgamation with mercury; while the ore in the unaltered parts of the deposit cannot usually be thus easily extracted, but must be smelted or treated by chlorination or some other more or less expensive process.

When such deposits as those described are eroded, the particles of gold separate from the quartz and are concentrated in the streams as placer gold. These detrital deposits are the source of a large part of the gold of commerce, and, in fact, were once the source of most of it. Now, however, many of the richest placer deposits known have been exhausted; and besides, the methods of treating the ores in the original deposits are better understood, so that the latter are supplying yearly a larger and

larger percentage of the gold production of the world. Hence, it will be seen, that in gold deposits, surface alteration not only plays an important part in freeing the gold from the iron pyrites, but also in forming placer deposits. Detrital deposits similar to gold placers and carrying various other materials are not at all uncommon, as in the cases of the platinum group of metals, cassiterite, diamonds and many other gems, chromite and magnetite sands, and, in fact, even with some of the more common ores, as with the iron conglomerate at Iron Mountain, Missouri.

Alteration in tin deposits.—In tin deposits, the typical mode of occurrence of the metal is in veins, dikes, or country rocks, in the form of the oxide known as cassiterite. Cassiterite is not easily affected chemically by surface influences, so that it is not much changed by superficial alteration, but for this very reason, its concentration is most markedly affected by surface alteration, for in the erosion of tin-bearing deposits the masses of cassiterite are broken up and carried off mechanically by surface waters, to be deposited somewhere else in the form of gravel beds, instead of being dissolved and possibly disseminated. In this transition, the fragments of cassiterite are largely separated from the accompanying materials by reason of their greater specific gravity, and hence, gravel deposits rich in cassiterite frequently occur. These represent the stream tin of the miner, and have been formed in much the same manner as have the placer gold deposits. Some chemical action, however, has gone on in the tin ore itself, but this seems to have been simply a process of solution and redeposition, as is seen in the pseudomorphs of cassiterite after other minerals and in the impregnations of animal remains in Cornwall, such as antlers, with oxide of tin.[1]

Alteration in antimony deposits.—In many antimony deposits, alteration similar to that described in some of the deposits already mentioned frequently occurs. The metal occurs most commonly as the sulphide known as stibnite. By alteration, however, this passes into the oxides valentinite, senarmontite, cervantite, stibiconite, etc., or into the combined sulphide and oxide known

[1] J. H. COLLINS, Mineralogical Magazine, Vol. IV., 1882, p. 115.

as kermesite. Valentinite and senarmontite have the same chemical composition but differ in their crystalline forms. Native antimony sometimes occurs, and this also, by alteration, gives rise to the oxides.

Alteration in bismuth deposits.—The allied metal bismuth occurs most commonly as native bismuth, though the sulphide (bismuthinite), the selenide (guanajuatite), the telluride (tetradymite), etc. also occur. Native bismuth, by alteration, forms the carbonate (bismutite) and probably also the oxide (bismite) and the silicate (eulytite).

Alteration in mercury deposits.—In the case of mercury the metal commonly occurs as the sulphide (cinnabar), though other mercury minerals also occur. By the alteration of cinnabar and some of the other mercury minerals, metallic mercury is set free and occurs as globules or filling cavities in the ore.

Alteration in molybdenum deposits.—Another case of surface alteration in metalliferous deposits is that seen in molybdenite. This mineral is the sulphide of the metal molybdenum, and often occurs in quartz or calcite veins in the crystalline rocks of parts of Canada, and in many ore deposits of the Rocky Mountains and elsewhere. By surface oxidation, molybdenite passes into a brilliant yellow oxide of molybdenum, commonly known as molybdite or molybdic ocher, which, in the Canadian region, occurs as a powdery coating on the cleavage planes of the molybdenite.

Alteration in other deposits.—Superficial alteration like that already described in various deposits, occurs also in many others not yet mentioned, as in aluminum, nickel, cobalt, chromium, tungsten, and many rarer deposits, but the changes already described show the general features of the subject. It may be said, however, that one of the important ores of aluminum, known as bauxite, is probably derived from the alteration of feldspar under certain conditions; and its source, therefore, is not altogether unlike that of the hydrous sesquioxide of iron derived from the alteration of certain silicates. The conditions during formation, however, were probably quite different.

THE FORMATION OF HALOID COMPOUNDS IN ORE DEPOSITS IN ARID REGIONS.

The formation of chlorides and other haloid compounds has already been mentioned as one of the phenomena of superficial alteration in ore deposits. As soluble chlorides and sometimes other haloid compounds are common in surface waters, chlorides and the allied compounds are not at all uncommon as alteration products, especially in such cases as that of silver, where the chloride, bromide and iodide are insoluble compounds, and are not leached out. For this reason, chloride ores of silver are found to a greater or less extent in almost all silver districts in America, Europe, and elsewhere, but the occurrence of such compounds in very large quantities in certain parts of North and South America deserves special explanation.

Over a large part of the arid region of the west, lying between the Rocky Mountains and the Sierra Nevada, ores containing chloride of silver (cerargyrite) are abundant, and sometimes the bromides and iodides also occur ; in fact, parts of this region are characterized by chloride ores. They are especially well developed in parts of New Mexico, Arizona, Utah, Nevada and other states and territories, and it seems probable that their abundance can be traced to the effect of the peculiar climatic conditions which have prevailed in that region in late geologic times. Most of this arid country was once covered with numerous bodies of water, some of them of great size. In late geologic times, however, these began to dry up, until their waters no longer rose high enough to have outlets, and then, as a natural result, they became highly impregnated with salt and other saline matter. Finally, they became desiccated, leaving deposits of various earthy and saline materials in their old basins, and among the most common of these was common salt. It seems probable that the abundance of chloride ores is due to the action of this salt on the pre-existing ore deposits of the region, in the basins of the lakes, and that the smaller quantities of bromides and iodides were formed by a similar action of the soluble

bromides and iodides in association with the salt. Such ores, in some of the mines that have gone to sufficient depths, have passed into various other silver compounds, such as the sulphide (argentite), argentiferous galena, etc., which represent the original condition of the ores. This transition proves the chlorides and other haloid compounds to be of only superficial extent.

This transition to haloid compounds is not confined to silver ores, for the basic chloride of copper (atacamite) occurs at Jerome in Arizona, and both chlorides and bromides of copper occur in the Bloody Tanks district west of Globe in Arizona, though here, as elsewhere in Arizona, the other copper minerals already mentioned, such as carbonates, sulphides, etc., form the bulk of the copper deposits.

In parts of Mexico, Chile, and Peru, where saline materials have collected in a manner somewhat similar to that in the arid regions of the United States, the chloride of silver is one of the important ores mined, and it sometimes occurs intimately mixed with chloride of sodium, or common salt, forming the mineral huantajayite or the lechedor of the miners. The bromides of silver are also abundant in Chile, and, in fact, at the mines of Chañarcillo, a common ore is the double chloride and bromide known as embolite. Again, the atacamite, or basic chloride of copper, from the Desert of Atacama is well known.

It seems probable that this transformation of the silver and copper minerals did not necessarily occur exclusively while the deposits were covered by saline lakes, but may have occurred even more actively afterwards, when the surface waters were highly impregnated with chlorides from the residue left by the lakes, and when oxidation in the ore deposits was much more active than when they were covered by water. This seems all the more likely when we consider that the original silver and copper minerals probably had to be oxidized before they were converted to chlorides, etc. Of course the oxidation may have partly occurred before, or during, the existence of the lakes, but

in many cases it probably also occurred after they were desiccated.[1]

SUMMARY.

It will be seen from the above discussion that:

(1) After the deposition of ore deposits and their subsequent exposure to surface influences, such as air, water and the materials contained in it, changes of temperature, etc., chemical and physical alterations occur which cause a total change in the mineralogical condition, and generally in the economic value, of the ore deposit.

(2) The process of this alteration is primarily one of oxidation and generally of hydration, and both of these actions may go on alone, but generally both have their effect on the same material. The other materials in solution in surface waters also react on the substances in the ore deposit, either before or after the oxidation of the latter, though generally after at least partial oxidation, and form various compounds different from those originally in the deposit. The difference, however, with few exceptions, is not in the metal or other base which forms the important feature of the deposit, but in the acidic portion or material representing this portion of the mineral. Thus, sulphide of copper may be altered to carbonate of copper, but the base remains the same. The action of surface influences is in rare cases one of reduction, which, however, often follows a previous oxidation. The process of alteration also frequently causes a leaching of certain ingredients of the ore deposit, either with or without previous oxidation, as in the removal of iron pyrites, calcite, etc. It also sometimes renders a hitherto worthless material valuable by the introduction of a valuable constituent, as in the replacement of carbonate of lime by phosphate of lime. It also causes the concentration, by capillary action in soils, of certain deposits like nitre, etc. The compounds formed with different ore deposits vary with the ores affected and the sta-

[1] Chlorides of other materials than silver and copper may also have been formed by a similar process, but the solubility of many metallic chlorides would prevent their being accumulated in any but very dry regions.

bility of the compounds formed by the action of the materials in the surface waters on the constituents of the ores.

(3) The physical effect of superficial alteration is generally to make the deposit more open an porous, to cause it to shrink, and, in some cases, to convert it to a loose material of the consistency of sand and clay. In some cases, however, especially where hydration is active, and expansion may be caused.

(4) Superficial alteration extends downwards as far as surface influences are able to act, though generally alteration is not complete down to the possible limit. The depth of alteration depends on the topography of the region, the nature of the rocks, and on the climate. In glaciated regions, the glacial action has swept away the products of alteration, and sufficient time has not yet elapsed since then for alteration to have gone on to any great extent, but in many other regions the products of alteration have accumulated to considerable depths. The depth of alteration, under different conditions, varies from a fraction of a foot to 1,500 feet, or possibly more.

(5) Superficial alteration is well illustrated in iron, manganese, copper, lead, zinc, silver, gold, tin, and many other deposits. For special descriptions see text.

(6) The accumulation of soluble saline materials, like salt, on the surface has a very important effect in converting certain materials in underlying ore deposits to chlorides, etc.

R. A. F. PENROSE, JR.

Studies for Students.

EROSION, TRANSPORTATION, AND SEDIMENTATION PERFORMED BY THE ATMOSPHERE.

In dynamical geology there is one line of inquiry which has received, comparatively speaking, but little attention from American geologists. Our text-books discuss in a thorough manner the work performed by water, and they also tell us much about the work of earthquakes, of volcanoes, and of glaciers. Some of these phenomena appear so striking as always to challenge our attention. Others are so common in their occurrence and so obvious that they suggest themselves to our study and to our reflection everywhere. The work performed by the winds in the atmosphere appears hardly to have received its due share of attention. The transportation of solid materials by the air is one of those subtle operations in nature, which are apt to escape our observation. The process is of an unobstrusive nature, and only in certain localities becomes at all obvious. There are, however, some scientists who have understood and urged the great importance and efficacy of aerial transportation in geological dynamics. Ehrenberg, Von Richthofen and Pumpelly will be remembered first in this connection. Blake, Gilbert, Hayden, N. H. Winchell, Chamberlin, Merrill, and others have described instances of erosion and transportation by the atmosphere. But it will be conceded, I think, that the subject has not received any general and searching attention from geological students in this country. This is the only excuse for presenting at this time a few considerations bearing on the topic. I take the liberty to state in a dogmatic way what appear to me to be some laws governing aerial erosion, transportation and sedimentation in general. It is not claimed that these statements contain much that is new in substance.

As an agent of erosion air is far less efficient than water.

The chief circumstance on which this inefficiency depends is the small weight of the air, which is only about $\frac{1}{813}$ as heavy as water. Moving with the same velocity it will strike with a force only $\frac{1}{813}$ as great as that with which water will strike. The effectiveness of the impact, however, or the striking force, increases as the square of the velocity and thus when the velocity of the wind is 28 (—813=28) times greater than that of a current of water, the impinging force of the two currents is the same. Velocities 28 times greater than those of many rivers are not uncommon in the air a small distance above the ground. But the lightness of the air enables even a scanty vegetation to greatly slacken the speed in the currents immediately in contact with the ground. This slackening of the impinging current is apparently sufficient to effectually protect even loose soil from wind erosion under ordinary circumstances. Such is at least the case where the soil is moist and where the land is level.

As an erosive agent, the atmosphere is at a disadvantage also in another respect. Lakes never erode their bottoms below the plane of wave action, and even in rivers erosion is greatest at the shores where this plane meets the land surface. Were it not for the wave action, the erosion by continental waters, as well as by the waters of the oceans, would be greatly reduced in its efficacy. In fact we generally look at that part of the surface of the earth which is under water, as being an area of deposition and sedimentation, and at the land above water and the coast lines alone, as being areas of erosion. Whatever be the height of the atmosphere, it does not appear likely that its upper limit is a well defined plane with waves as on the sea. But even if it be, this wave plane would be high above the most elevated point on the earth's surface. There is, therefore, no plane of wave-erosion in the atmospheric sea. Such work of this kind as is performed by the air can only be compared with that which takes place in the ocean far below its plane of wave-action, and rather in its abysmal region. Evidently this is not very great, if of any consequence at all.

Wind erosion becomes geologically important only in certain localities, and the conditions favoring it are a dry climate and a topography of abrupt and broken reliefs.

On plains where the ground is dry and vegetation scanty or absent, ordinary strong winds are apt to slowly wear into the soil, where the roots of plants do not protect it. If such soil contains sand which is too coarse to be lifted up and carried away, dunes are formed, and the uneven topography thus developed still more favors wind erosion; for it is evident that the slopes of the dunes will be struck with greater force than the even surface of a level plain. In such places the sand grains are triturated and worn, and the abraded material is promptly removed. It is also evident that where a country is traversed by vertical escarpments and cliffs, and steep slopes, strong eddies are set up as the wind strikes these reliefs. Where the rocks are of fine materials and but little indurated, like most of the Mesozoic and Cenozoic beds of the west, it would be singular if such eddies did not erode the bare surfaces of their outcrops. It does not appear practicable to estimate separately the erosion produced by impact of the air alone, and the abrasion produced by the materials carried. The ratio between the two will, of course, vary with the quantity of the load. Where this is considerable, abrasion is no doubt proportionally greater than in water, for the speed of the impinging particles is here much higher, and their striking force consequently greater. Occasionally this circumstance greatly intensifies aerial erosion and produces a natural sand-blast, which is very effective in its action on solid rock. That such abrasion becomes appreciable and important along the escarpments of "mesas" in dry regions appears not to admit of a doubt. In such places the driven sand may sometimes be felt smiting the exposed skin of the traveler.

The speed of the wind being lowest near the surface of the ground, materials must by some means be lifted through this zone of low velocity in order to be transported any considerable distance by the atmosphere.

According to some observations made by Stevenson, the aver-

age velocity of the wind increases very fast and apparently not according to any definite law upwards for the first fifteen feet above the ground. Above this height it increases as the bisected chords of parabolas having their vertices in a horizontal line 72 feet below the surface. The parameters of these parabolas increase directly in the ratio of the squares of the velocities of the different winds. With a velocity of ten miles per hour at an elevation of fifty feet above the ground there will then be a velocity of about one hundred miles per hour one mile above the ground, but of less than one mile per hour near the surface. Observations made on the movements of clouds verify these calculations as to high velocities some distance up in the atmosphere. Whatever is to be transported any great distance must be lifted up to some considerable height above the surface of the earth, where the winds attain high velocities.

Over level plains, under ordinary circumstances, the conditions seem to be unfavorable for effecting any such upward transference, and little or no removal of material is apt to take place. But when a strong wind runs up against a vertical cliff, such as are seen in the bad lands or in the country of the plateaus and "mesas," eddies are no doubt set up which rise high above these vertical reliefs. A short valley or a reëntrant excavation in such a cliff will gather the wind and start it with increased force obliquely upwards, as it enters from the open end. In such a mobile element as the atmosphere an eddy like this may rise a considerable distance. No less effective in this respect are the whirlwinds in arid regions, which have been described by nearly every traveler in such countries.[1] During the warm part of the day these can be seen, it is said, at almost any time in some direction of the horizon. They often rise to a great height, carrying with them the loose materials of the desiccated soil and giving them up to the incessant and steady run of the winds above.

The explosive outburst of a volcano similarly launches enormous quantities of minute fragments of pumice on the currents

[1] Geo. P. Merrill, Engineering Magazine, Vol. II., p. 599 *et seq.*

of the atmospheric ocean, throwing them upwards sometimes over 10,000 feet. Small quantities of incombustible matter are raised to the horizon of translation above by heated currents of air from chimneys and fires, and perhaps still smaller quantities by birds and other animals of flight.

Aside from these instances there are no important means by which the atmosphere is loaded, and for this reason, among others, its importance as a geological agent is small. The load to be carried must be raised before it is borne away. In water the contrary is almost always the case. The material to be transported is supplied at the water's surface and from the start to the end of the transport the sediments are allowed to slowly sink. They are transported forward and downward; in the atmosphere they must be transported first upward, and then forward.

To be subject to transportation by the atmosphere, rock materials must be finely comminuted, the average largest size of quartz particles that can be sustained in the air by ordinary strong winds being about .1 mm. in diameter.

This statement is based on a number of measurements, which have been made on sand and dust transported by the air. Among these are measurements of dust and sand raised by the wind from roads and streets in dry weather; of dust which fell on the ground at Kansas City, Mo., after a severe west wind on the plains; of dust collected after dry storms on the window-sills in residences in the central part of Kansas; of sand taken in crevices and corners in railroad cars in various parts of the country. It agrees with measurements made on volcanic dust known to have been carried several hundred miles in the atmosphere. Corroborating results have also been obtained by some simple experiments. The constituent materials of a coarse loam were separated into groups of different grades of fineness. These separations were thrown into the air and observations made on their behavior. The velocity of the wind was about eight miles per hour, and the observations may be tabulated as follows:

Average diameter of particles.	*Behavior of the particles when thrown into the air.*
.75 mm.	Described a path diverging about 10° from a vertical line.
.37 mm.	Described a path diverging about 45° from a vertical line.
.18 mm.	Described a path diverging but a few degrees from a horizontal line, were blown upward by eddies.
.08 mm.	Could scarcely be noticed to settle in transport.
.04 mm.	Apparently completely borne up by the wind.
.007 mm.	Completely borne up by the wind.
.001 mm.	Completely borne up by the wind.

It is hardly necessary to add that the average size of the largest particles carried varies greatly with the velocity of the wind. Sand grains will occasionally be found to have been thus carried, which have a diameter many times larger than the average maximum here stated. The presence of such large grains can readily be accounted for by the chances for becoming entangled in specifically lighter objects, such as fragments of leaves and other vegetation, and thus to be carried by them. It will be understood, also, that the statement made above does not apply to that phase of wind-transportation which takes place on the surface of a sand-dune, where the sand is as if rolled forwards, nor to that in the very lowest part of the atmosphere generally, where materials are thrown forwards short distances at a time by eddies due to the contact of the atmosphere with the more or less irregular surface of the land.

The capacity of the atmosphere for transporting particles of quartz below the size of .1 mm. in diameter, is very great.

Disregarding the occasional transference of matter by volcanic forces and by living organisms, there are only three principal agents known to be at work removing materials from place to place on the surface of the globe. These are water, ice, and air. It is believed that, with the above limitation as to the fineness of the material, the transporting power of the atmosphere, as compared with that of water and ice, is very great. The transporting capacity of the water in our continental rivers is better known than that of glaciers or of ice fields, and it makes our best

standard of comparison. Let us take, for instance, the work of transportation which is performed by the Mississippi river.

The efficiency of any transporting current is determined by three factors, viz. : (1) the area of its transverse section, (2) the velocity of its motion, and (3) its capacity for holding a load. In the case of the Mississippi basin we may say that the products of disintegration and erosion within its boundaries may be removed by principally two agents, water and air. What is removed by water all passes out through the channel of the lower Mississippi. The size of this current in transverse section is less than $\frac{1}{100}$ of a square mile. It is evident that all the materials removed by this river from its great basin, whether taken from the Rocky mountains or from the Appalachian highlands, must pass through the same narrow circumscribed limits of $\frac{1}{100}$ of a square mile in the lower course of the river. Now, the atmosphere may also be regarded as a current. The width of this current will be the average width of the entire drainage basin of the Mississippi, and in its height this current equals the height of the atmosphere. Taking this to be ten miles, which cannot very well be too much, and taking the average width of the Mississippi basin as one thousand miles—it is at least one hundred miles more—the transverse section of the atmospheric current will be ten thousand square miles. The ratio of the sizes of these two currents as shown in their sections is thus 1 : 1,000,000, *i. e.*, the cross section of the Mississippi current is $\frac{1}{1000000}$ of that of the atmosphere. If velocity and capacity for carrying a load were the same in both currents, the relative transporting power of the greater one would be 1,000,000 times that of the smaller.

In respect to velocity the Mississippi is also less effective in its work than the atmosphere above it. The average velocity of the wind over the interior basin is not less than eight miles per hour, while the average velocity of the lower Mississippi is about .7 mile per hour. The ratio of the velocities is therefore represented by the fraction $\frac{7}{80}$, which is a little less than $\frac{1}{10}$. If, therefore, the two currents were equal as to their cross sec-

tions and as to their capacity for sustaining a load, the current with the greater velocity would be able to remove ten units of sediments, while the slower current would remove one. Multiplying the fraction expressing the ratios between the cross sections of the two currents ($\frac{1}{1000000}$) by the fraction expressing the ratio between their velocities ($\frac{1}{10}$), we obtain a fraction which expresses their relative carrying power, if their capacities for sustaining a load were the same. This fraction is $\frac{1}{10000000}$. If every cubic foot of air in the atmosphere held in suspension as much of sediments as every cubic foot of water in the Mississippi, then the atmosphere would have the power to transport in a given time ten million times the quantity of material transported in the same time by the Mississippi river.

With regard to the capacity for holding solid particles in suspension the air is, however, greatly inferior to water. It is evident that the load which can be carried by the air at ordinary and even in high velocities, is a great deal smaller than that which can be carried by water. The capacity in this respect of any current depends on chiefly three factors: (1) the density of the medium, (2) its velocity, and (3) its viscosity. As to the comparative densities of the two fluids, the air is only $\frac{1}{813}$ times as heavy as water. Another circumstance also comes into consideration. When the particles of a material like quartz are suspended in water, they lose about $\frac{10}{26}$ of their weight in the air, and the force with which they make their way downwards through the water is thus reduced to $\frac{16}{26}$ of what it would be in the air. This still more increases the relative carrying power of water making it 1321 times as great as that of the air ($813(\frac{26}{16}) = 1321$). On account of the greater average velocity of the atmosphere and also by reason of the consequent greater magnitude of its convection currents, this again has the advantage over water. But exactly to what extent these considerations affect the comparison, data are not at hand to determine. It would appear that the advantage connected with these greater convection currents more than outweighs the disadvantage due to the lesser viscosity of air, when compared with water. At such low

velocities and temperatures this difference in viscosity can perhaps be altogether disregarded. The relative power of the atmosphere to sustain a load of fine sediments would, therefore, appear to be no more than, say $\frac{1}{2000}$ of that of river water. But to be certain that this estimate shall not be too high, let us make the fraction $\frac{1}{5}$ of this value and call it $\frac{1}{10000}$. This means that if a cubic foot of water, *e. g.*, in the Mississippi, will hold in suspension 15.48 grams of solid particles[1], then the atmosphere above it can hold in the same manner in a cubic foot $\frac{1}{10000}$ of this quantity, or about .0015 gram. It will be remembered that this is true only for material of a certain coarseness. If it is too coarse, the atmosphere cannot hold it at all; while if it is very fine, considerably more can no doubt be sustained. In order to ascertain approximately the effect of the variation of the size of the particles on the quantity of materials which can be thus suspended in the air, and also to make sure that the above estimate of the total load of sediments which can be sustained is not too high, some simple experiments have been made. These consisted in introducing dust of varied degrees of coarseness into a receiver, and then keeping the air in the receiver in constant agitation at a velocity of about five miles per hour. A certain quantity of dust would in this manner be kept floating in the circulating air, and this quantity was found to vary with the nature of the material introduced. The results may be tabulated as follows:

Average diameter of particles.	*Quantity sustained in one cubic foot of air agitated to an average velocity of 5 mi. per hour.*
.08 mm.	.020 gram.
.04 mm.	.057 "
.007 mm.	.118 "
.001 mm. (and below)	.053 "

This apparently amply justifies the above estimate as to the quantity of dust which can be sustained in a certain bulk of atmospheric air. It is not supposed that the table gives exact determinations for the different materials, for the conditions of

[1] Humphreys and Abbott.

the experiment are of the most delicate kind and a slight change in the velocity will cause a considerable variation in the quantity of the load.

If then the ratio of the sections of the two currents is $\frac{1}{1000000}$, the ratio of their velocities $\frac{1}{10}$, and the ratio of their loads per unit of bulk of the two media is $\frac{10000}{1}$, the ratio of their respective transporting powers is as the products of these fractions, or $\frac{1}{1000}$. This is the same as to say, that if a cubic foot of air can hold in suspension $\frac{1}{10000}$ of the quantity of fine dust held in the same way by the water in the Mississippi river, and if the velocity of the winds in the atmosphere is on the average not less than ten times as great as the rapidity of the current in the river, and if the area of a vertical section of the atmosphere over the valley is 1,000,000 times as large as the area of a cross section of the lower stream,—then the capacity of the atmosphere to transport dust is 1,000 times as great as that of the river.

Atmospheric currents being loaded, mostly, only to the extent of an insignificant fraction of their capacity, their sediments will be better sorted than deposits in water-currents, which are more often loaded to their full capacity.

It is evident that the greater the load carried by any current, the shorter is the average distance from particle to particle while in transport. This increases the chances for the particles to be affected by each others' movements through the medium and thus for coming together to form clusters. This process, which has been called flocculation, causes more rapid sedimentation; for such a cluster of particles will fall faster through the medium than will the separate grains of which it is composed. Flocculation takes place among particles of all sizes, and small particles which would otherwise be retained in the supporting medium, will easily settle when collected into these clusters. Sediments which have been formed under such circumstances will hence contain a proportionally greater quantity of fine material than if flocculation had not taken place. But flocculation increases with the quantity of the load, and since the load of the atmosphere is

at least 1,000 times (under ordinary circumstances perhaps nearer 100,000 times) less per unit of bulk of the carrier than in most waters where sedimentation occurs, it is likely true that flocculation in aerial sediments is not as great as that which takes place in aqueous sediments. Thus the finest materials carried by the air are not deposited in so great a proportion with the coarse material, as they would be if the atmosphere carried a greater load. The finest sediments, say particles below .002 mm. in diameter, settle only during extreme calms, if not first caused to gather in flocculi. This extremely fine material is retained by the atmosphere and must be carried everywhere over the entire surface of the globe, and must also be deposited everywhere, but in such small quantities as not to be noticeable. No small part of it, it may be surmised, is carried from the land and precipitated into the sea. But the coarser sediments, say particles between .002 and .1 mm. in diameter, are less easily retained in the air and therefore occasionally deposited in favorable localities in such quantities as to become an object of geological significance. It is maintained that in these deposits from the atmosphere there should be a scarcity of the finest materials.

It should be remembered, however, that there are great differences in the prevailing wind velocities and that this circumstance will naturally bring together materials ranging through great differences in coarseness. It has lately been shown[1] that such differences are great, even within the limits of a minute of time. As a result there will be a chance for a considerable range in size of particles composing the bulk of any aerial sediment, a range which it is believed might be expressed for the diameters of such particles by the numbers 1 and 100. Of course the range of the extremes will be much greater.

Deposition of dust will take place where wind is caused to slacken its speed.

This is so self-evident that it appears superfluous to mention it. It may be presumed that such a slackening will take place over continental basins, where the general direction of the wind's

[1] S. P. LANGLEY: Internal Work of the Wind.

progress is transverse to the bounding highlands. It may also be presumed that the wind retards its velocity, when going down an inclined plane. The greater depth of the atmospheric ocean in these instances ought to have the same influence on the general current as the widening or deepening of a river channel. If this be the case with extensive continental depressions, valleys of rivers and smaller depressions of the earth's surface ought to produce somewhat similar effects in retarding the passing wind and inducing it to give up a part of the dust it may happen to carry along. On the other hand, when the wind passes over land covered by a growth of timber or only tall grass, its lowest part will be held comparatively still and will drop its load. Did the same air remain among the vegetation all the time this unloading process would stop with the first deposit, but as the eddies no doubt keep up a slow but constant exchange with the air above, the accumulation continues as long as there is any dust left.

Several important deductions can be drawn from the foregoing considerations.

The velocities in the atmosphere being so much greater than those obtaining in rivers, lakes, and seas, the distances over which materials may be transported in it will be correspondingly greater. In the sea sediments are carried out 200 miles and even farther. In the atmosphere, where the velocities often are 100 times greater than those in the sea, dust may, no doubt, be transferred a distance of several hundreds, if not a few thousands of miles. The very finest particles may be borne round the earth, as shown by the dust of Krakatoa, or may, indeed, circle about it for some time.

The greater depth of the aerial ocean renders it but little dependent in its movements on smaller elevations of the land. In a sea five miles deep an elevation of the bottom 8,000 feet high would interpose no serious obstacle to a general forward movement of the whole body of the fluid. Few of our mountain ranges exceed this height, and it would not seem impossible, therefore, that dust in some notable quantities should be carried

across a mountain range, provided there be a favorable current in the upper part of the atmosphere.

While the conditions requisite for much aerial erosion are limited to rather small areas on the land of the globe, there can be little doubt that deposition is much more general and widespread. For dust is carried everywhere. And if it be conceded that the atmosphere is never entirely free from dust, it follows that sedimentation occurs wherever and whenever there is a comparative calm. In places in the ocean, where sedimentation is known to be very slow, atmospheric dust may be supposed to form an appreciable part of the deposits.

The areas of deposition being much greater than the areas of erosion, it is evident the accumulations of atmospheric sediments as a rule are insignificant, only exceptionally exceeding on the land the secular erosion by water, and therefore accumulating only in such exceptional cases.

From a dynamical point of view the wind-theory would appear to furnish an adequate explanation of the occurrence of the loess in the Mississippi valley, at least as to most of its phases. The recent denudation of the western plains, of the bad lands, and of the Cordilleran plateau is extensive enough to furnish the materials many times over. The different rocks in these regions and the changeability of the atmospheric currents would combine to bring together and thoroughly mix a variety of materials, like those of which the loess is composed. The winds would naturally distribute over wide areas the heterogeneous but uniform mixture thus produced. When not taken close to exposures of other materials ninety-nine per cent, by weight, of the loess is composed of particles below the size of .1 mm. and it contains only a small proportion of the finest materials common in clays and residuary earths, just as must be the case in an atmospheric sediment. In the United States, lying in the zone of westerly winds, we find the loess in the continental basin east of the arid regions. It is best developed along the westernmost north-and-south drainage valley, that of the Missouri-Mississippi river. Almost everywhere it is heaviest nearest the

watercourses. In northeastern Iowa its distribution shows such remarkable coincidences with the distribution of the primeval forests, as to only leave the uncertainty whether the loess is the cause of the growing of the forest or the forest the cause of the accumulation of the loess.[1]

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[1] See Pl. XXII and XLIV, Eleventh An. Rep. U. S. Geol. Survey. MCGEE.

EDITORIALS.

THE circular of information regarding the Sixth International Congress of Geologists, to be held at Zurich from August 29th to September 2d, presents a most inviting programme of excursions, which may be taken by members of the Congress, in the picturesque and geologically famous regions of the Swiss Alps and the neighboring Jura Mountains. It is proposed to organize two groups of excursions conducted by geologists, many of whom have devoted the better part of their lives to the investigation of the country visited. The first group will be offered immediately before the meeting of the Congress, and is so arranged that those participating in them will arrive at Zurich a day or two before the opening of the Congress. These excursions will be devoted to various portions of the Jura Mountains. They will be organized in different towns, where those intending to take the excursions are to join the conductors of the parties. The second group of excursions take place immediately after the Congress adjourns, and will start from Zurich on September 3d, and will traverse the Alps by various routes, terminating at Lugano, about September 16th, where the Congress will be formally closed. There will be two classes of excursions. One class will be made on foot, in order that the geology of the country may be more carefully examined. The other will be by means of conveyances. The pedestrian excursions will necessarily be open to a limited number of persons, and warning is served that a certain amount of quasi-military discipline will be required by the leader, from which appeal may be made to the whole body of participants. The expediency of such a regulation will be apparent to all who have attempted to conduct similar tours. The second class of excursions will make use of railways, steamboats and carriages, and will aim to reduce to a minimum the distance to be gone over on

foot. The management of the details of transportation of these excursions will be entrusted to the agency of Messrs. Ruffieux and Ruchonnet at Lausanne ; their scientific direction will be undertaken by Professor Renevier and Professor Golliez, of the University of Lausanne, The first excursion of this sort will start from Geneva, where those participating in it will assemble on the 15th of August, and will spend thirteen days visiting localities in or near the Jura, including the environs of Geneva, Lausanne, Neuchâtel, Bâle, and the Falls of the Rhine. The second of these "voyages en zig-zag" will start from Zurich on September 3d, and will spend thirteen days in the most delightful parts of the Alps, visiting, among other points, the Rigi, St. Gothard, the Lake of the Four Cantons, the Jungfrau, the Matterhorn, and the Italian lakes. The cost of the first excursion is to be $60, and of the second $80.

Of the pedestrian tours, five are to take place before the meeting at Zurich. One, under the direction of Professor Schardt, of Montreux, will devote six days to the French Jura in the neighborhood of Geneva, the rendezvous being at Geneva, August 21st. The second, conducted by Professor Jaccard, of Neuchâtel, will spend five days in the Jura of Vaudois and in the neighborhood of Neuchâtel. The rendezvous is to be at Pontarlier, August 22d. The third excursion, in charge of M. Rollier, of Bienne, will spend six days in the Bernese Jura, the rendezvous at Delémont, August 21st. The fourth, under the direction of Professor C. Schmidt, of Bâle, will devote five days to the vicinity of Bâle and the country east of the Argovian Jura ; the rendezvous at Bâle, August 21st. The fifth excursion, under Professor Mühlberg, of Aarau, will spend five days in the Argovian Jura and in the neighborhood of Soleure. The rendezvous will be at Aarau, August 23d.

There will be four pedestrian tours after the meeting of the Congress, one under the leadership of Professor Heim, of Zurich, who will conduct a party over the eastern Alps of Switzerland from St. Gallen to Tessin, studying the compressed folds in the Säntis, and crossing the great Glärner double fold. Professor C.

Schmidt will conduct a party over the central Alps from Zurich to Lugano, visiting the "cliffs" of the Mythen and following the Gothard route across the crystalline axis of the Alps. Professor Baltzer, of Bern, will conduct another party over the Bernese Alps, from Lucerne to Tessin, examining the intricately plicated strata of the Gstellihorn, passing over the Grimsel and visiting the glaciers of the Unteraar and the Rhône. Professor Schardt will lead a party over the western Swiss Alps from Bulle, studying the complicated structure of the Alps of Freiburg, and crossing the Tête-Noire to Domo-d' Ossola. These excursions will furnish foreign geologists the best possible opportunity of becoming acquainted with the complex structure and widespread metamorphism which have become classic through the untiring energy and intelligent investigation of the Swiss Geologists. It goes without saying that all who can find the time and means at their command will avail themselves of these exceptional opportunities, and that the Sixth International Congress of Geologists will surpass its predecessors both in the number of members attending and in the benefits derived from the meeting.

J. P. I.

REVIEWS.

Geological Survey of Georgia: The Paleozoic Group: The Geology of Ten Counties of Northwestern Georgia, and Resources. By J. W. SPENCER, A.M., PH.D., F.G.S. (L. and A.), State Geologist. Published by Authority. Atlanta, Ga. Geo. W. Harrison, State Printer, 1893.

The state of Georgia has been somewhat unfortunate in the matter of Geological Surveys. That under the direction of Dr. George Little was discontinued before the publication of any extended report upon the work accomplished, and thus the results of a number of years of field work by competent geologists were lost to the state. The survey under Dr. Spencer was from the first heavily handicapped by the action of the Advisory Board in appointing the assistants without consultation with the State Geologist. It seems probable that this action of the Board will have the result of causing the loss to the state of all the work of the assistants so appointed. It is very much to be hoped that the Advisory Board will profit by past experience, and under the new organization will leave the choice of his assistants to the State Geologist, Professor Yeates, who is the successor of Dr. Spencer in this important position. Under no other conditions could a geologist with any justice be held responsible for the conduct and results of a survey.

The present volume records the work of Dr. Spencer in the Paleozoic terrane of Georgia, and a previously published report has dealt with the Tertiary and newer formations of the southern part of the state.

In chapter I, there is a general sketch of the geological structure of northwestern Georgia, in which are discussed in general terms, and in non-technical language, the formation and destruction of rocks; the effects of terrestrial movements on the growth of strata; the disturbances and dislocations of the original beds; the origin of valleys. In chapter II, the formations of northwestern Georgia are given in tabular form, with their equivalents in other states; in general the names first proposed by Dr. Safford for Tennessee find acceptance in

this report, as they must with all who have to do with the Paleozoic formations of the states adjacent to Tennessee, for the descriptions and classifications of Dr. Safford are remarkably true to nature. Chapters III to VI inclusive are devoted to a general description of the lithological and other characters of the different formations which make up the area under consideration in Georgia. The Ocoee group, which Dr. Safford places at the base of the Cambrian in Tennessee, or beneath the oldest of the fossiliferous strata, is mentioned by Dr. Spencer, but he does not enter into its detailed description. This group of semi-crystalline slates, often designated as hydro-mica schists, talcoid schists, and formerly as talcose schists, and which bears the greater part of the auriferous quartz veins in Georgia and Alabama, is extremely difficult to assign to its proper place in the series, in Alabama at least, for we find in the southeastern part of the Alabama Paleozoic terrane, some of the Knox or Montevallo shales slightly altered into partially crystalline slates, which we have not yet been able to discriminate from the unquestioned Ocoee. It has therefore seemed to us at least possible that the Alabama representatives of the Ocoee of Tennessee may be, in part at least, altered Cambrian shales. In chapter VIII the river alluviums and other formations later than the Carboniferous are mentioned, and it is interesting to find that remnants of the Lafayette, in the form of pebbles and red loam, are to be found in many places in the Coosa Basin at elevations of 100 to 150 feet above the present level of the waters in those regions. These same beds have been traced by the Alabama survey up the Coosa valley to the Georgia line, and they are also to be found extending from the west, for a good many miles within the Alabama line along the Tennessee river.

In chapter IX, dealing with the general physical features of the region, Dr. Spencer directs attention to the ancient character of the streams, and concludes that they long ago reached their base level of erosion, and have since been engaged in widening their valleys. In comparatively modern times (Lafayette), there has been a depression which has allowed the deposition of pebbles and loams at altitudes 80 to 150 feet above the present stream level, and of course a still more recent movement of elevation which has brought the streams to their present position. Probably the most striking memorial of these movements is to be found in the "flatwoods" of the Coosa Valley. This chapter is illustrated by a number of sections. Chapters X to XX

inclusive, are devoted to the detailed description of the local geology of each of the counties embraced in this region.

Part II (chapters XXI–XL inclusive) deals with the Economic Resources of the Paleozoic group, which are limonite, hematite, manganese ores, beauxite, coal, limestones, sandstones, and clays. The mode of occurrence of these materials, their distribution both geographical and geological, their analyses, etc., are shown forth in sufficient detail, and a commendable feature of Dr. Spencer's treatment is found in the explanations and suggestions as to the origin of these various ores, expressed in terms which are easy of comprehension even by those who have not had any special geological or chemical training. In this way the book has a direct educational value apart from the great amount of information as to local occurrences which it contains. The chapter on beauxite is of special interest, because of recent developments in the mining and shipping of this valuable substance from the Georgia and Alabama mines. The occurrence and general character of the ore in the two states are identical, in fact the ores belong practically to a continuous deposit, in close connection with the strata of the Knox Dolomite. On account of competition with the foreign beauxites, only the higher grades of the ore, containing from 55 per cent. and upwards of alumina, are shipped, and by far the greater part of this goes to the making of *alum*. This seems a wanton waste, since the inferior grades would answer for alum, and the higher grades should be reserved for the manufacture of the metal.

The coal of Georgia is confined to an area of about 200 square miles on the plateaus of Sand and Lookout Mountains. It is furnished almost entirely by two or three seams lying between the Upper and Lower Conglomerates near the base of the Coal Measures, as is the case also in Tennessee and the Plateau region of Alabama. In all this territory, these seams and the strata by which they are separated, are exceedingly variable in thickness. The most widely distributed of these is the Castle Rock seam just below the Upper Conglomerate (Main Etna and Cliff seams of Alabama and Tennessee). In Georgia the Dade seam, some 30 feet or more below the preceding, appears to be more extensively worked, and, in the sections given, of greater average thickness. This seam also has been worked in Alabama, where it is known as the Eureka seam. Still below this in all the states mentioned is another seam of great importance locally, the Red Ash seam.

In one locality, Round Mountain, which rises above the Lookout

Table land as a prominent eminence, an important seam is described by Dr. Spencer, which lies many feet higher up in the measures, and which so far as we know does not occur in that part of Lookout Mountain that extends into Alabama.

The clays described are of several kinds, (1) the kaolin-like clays, (2) the residual clays from the decomposition of limestones and calcareous shales, (3) the clays formed from the disintegration of shales, and (4) the alluvial clays. The first variety occurs in "horses" or in sheets or pockets in the residual earths from the decomposition of the strata of the Knox Dolomite and Fort Payne series. These are often quite pure and white, and have nearly the theoretical composition of kaolin. Although they occur in the residual matters they are not, according to Dr. Spencer, *residua* of the limestones, but are derived from the rocks of the metamorphic series.

The residual clays produce sometimes fairly good brick, but they are generally too rich in fusible materials to make fine products. Of greatest promise are the clays derived from the disintegration of shales and slates, some of which have given beautiful vitrified brick, such as would probably be well suited to serve as paving brick. The alluvial clays, especially such as belong to the Second Bottom deposits, in Georgia as well as in Alabama and Mississippi, furnish by far the greater part of the material for the manufacture of ordinary building brick, and it is of interest to note that the best quality of building brick along the whole Appalachian region is made from deposits of this character.

In chapters XL and XLI we have a plea for better roads, with numerous illustrations of country roads in Europe and America, which emphasize sufficiently well the contrast between good roads and bad ones. This is a seasonable chapter in view of the great interest now being awakened in the subject of better roads throughout the southern states.

Part III, chapters XLII to XLIV, is devoted to the discussion of the origin and characteristics of the soils derived from the various Paleozoic formations, and the composition of these soils is shown also by a number of chemical analyses.

An appendix containing acknowledgments and an account of the progress of the Survey, a classified table of contents and a full index conclude the volume. The base of the map has been compiled chiefly from the topographic sheets of the U. S. Geological Survey, and in the

mapping of the geological formations, Dr. Spencer acknowledges the valuable aid which he has had from the previous work of Dr. C. W. Hayes in this territory. The map shows in a very clear and satisfactory manner the areal distribution of the formations. We cannot, however, speak so much in praise of the cross sections, in which the vertical scale is so greatly exaggerated as to be quite misleading.

We consider this the most important of the official documents yet issued by the State of Georgia, and it is to be regretted that during his term of office Dr. Spencer did not have that complete control of the Survey that would have insured the publication of other reports of equal importance, especially one on the Crystalline Schists of the state.

E. A. SMITH.

Annual Report of the Geological Survey of Arkansas for 1890; J. C. BRANNER, State Geologist; Volume IV., *Marbles and Other Limestones*, by T. C. HOPKINS, 8vo., 443 pp., illustrated by cuts and plates, and accompanied by an atlas containing six sheets.

THIS volume is the latest of the series of volumes published by the Geological Survey of Arkansas. It is separated into three divisions, which are sub-divided into twenty-eight chapters. The first division is the introductory chapter on the "General Description of the Marble Area." After this comes Part I., which treats of limestones, including the following topics: "Composition and Origin of Limestone," "Varieties of Limestone," "Geologic and Geographic Distribution of Limestones," "Limestone as a Building Stone," "Miscellaneous Uses of Limestone," "The Carboniferous Limestones of North Arkansas," "The Silurian Limestones of North Arkansas," "Carboniferous Limestones South of the Boston Mountains," and "The Lime Industry of Arkansas."

Part II. treats of marbles, including the following topics: "The Origin and Uses of Marbles," "Marble in the United States," "Marble in Other Countries," "Marbles of Arkansas," "St. Clair Marble," "The Distribution of the St. Clair Marble," "St. Joe Marble," "Distribution of the St. Joe Marble," "Other Marbles found in Arkansas," "Quarrying, and Cutting, Dressing and Polishing Marble." In addition to this there is an appendix treating of the "Faults of the Marble Area of Northern Arkansas." Like many of the other

reports of the Arkansas Survey, this volume does not confine the discussion of the subject to Arkansas alone, but treats it also as a general proposition, thereby adding greatly to the usefulness of the report.

The general synopsis of the volume, given above, defines its scope. The marbles and other limestones of Arkansas are very properly discussed more in detail than any others, but a general description of these materials in other parts of the United States, as well as in the more important foreign localities, is also given. The author has not only given his own experience and investigations in the subject in Arkansas and other regions, but has collected in a systematic manner a large amount of useful information published elsewhere. He discusses also very fully the geology and chemistry of marble and limestones in general, as well as their various uses for ornamental and structural purposes, for making cement, burnt lime, etc. The discussion of the best methods of working and utilizing marbles and limestones, together with the plates illustrating these processes, will be of much use to the people of Arkansas, as well as elsewhere, in developing industries of this kind. The volume is really to be considered a text-book on marbles and other limestones, and not a report on the occurrence of these materials in Arkansas alone, though the treatment of the subject as related to that state is of course given prominence.

One of the most remarkable points brought out in the volume is the immense amount of marble contained in the state. In a belt of country lying north of the Boston Mountains and extending from near the Black River on the east to beyond Eureka Springs on the west, a distance of more than 125 miles, the marble is continuous, and the length of its winding outcrops as mapped is 2,812 miles. The combined area of the six maps necessary to represent this marble region is 4,450 square miles. This area extends east and west along the north slope of the Boston Mountains, on both sides of the White River and its tributaries, which run southeasterly in a general direction parallel with the mountains. The rocks are approximately horizontal, or dip gently to the south, and the marbles, which occur in both Silurian and Lower Carboniferous horizons, are exposed where they have been cut through by the creeks and rivers. The marbles vary greatly in quality and color, but many of them have been proved by practical tests made under the direction of the Geological Survey, to be of great strength and excellent quality. In color they vary from white to gray, pink, red, brown, and black, the gray, pink, red, and brown colors being the most com-

mon. In texture they vary from close grained, compact and granular to coarsely crystalline.

In spite of the large quantity and good quality of much of this marble, very little of it has been utilized and practically none of it has been shipped for outside consumption. The country is only very sparsely settled, and this fact doubtless accounts for the limited local use of the marble; while the lack of shipments to outside localities is explained by the want of transportation facilities, the ignorance of the existence of this marble among those who use such materials, and by the fact that many people have obtained a bad impression of the stone in general on account of a certain very poor grade of Arkansas marble used in building at Eureka Springs. The whole marble region is destitute of railroads, except at Batesville on the eastern end, and Eureka Springs on the western end, so that the use of a poor grade of this marble at a much visited locality like the latter place, was an unfortunate occurrence. The present volume will, therefore, do much good in removing these several difficulties. It will show some of the benefits to be derived by those who will introduce railroads into this country, which, indeed, is full of other resources besides its marble; it will bring the marble to the attention of builders and architects and all others interested in ornamental and structural materials; and it will also tend to overcome the bad impression given by the use of an inferior marble at Eureka Springs. Even without further railway facilities, the marble, as shown by Mr. Hopkins, could be cheaply shipped by water on the White River.

The chapter on "Carboniferous Limestones South of the Boston Mountains," is by Mr. J. H. Means, and is a careful discussion of the subject involved.

In conclusion, it may be said that the volume, besides containing a full discussion of the subject of marbles and other limestones, also gives much information on the geology of North Arkansas, and represents a large amount of careful geological work. The report is of much scientific and economic value, and reflects great credit on both Mr. Hopkins, through whose labors the great amount of work represented in the volume and the accompanying maps has been accomplished, and on the State Geologist, Dr. Branner, by whose liberal and broad minded policy, as well as by whose kindly interest in all investigations carried on under his supervision, such work is possible.

R. A. F. PENROSE, JR.

ACKNOWLEDGMENTS.

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THE

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MAY-JUNE, 1894.

THE NORWEGIAN COAST PLAIN.

A NEW FEATURE OF THE GEOGRAPHY OF NORWAY.

THE western part of the Scandinavian peninsula is generally spoken of in geographical descriptions as simply sloping down to the sea. This is not exactly true, for there are, along the coast low, almost level tracts which I propose to unite under the term, The Norwegian Coast Plain. This plain begins on the seaward

FIG. 1. Mount Siggen rising above coast plain.

side with small, naked islands surrounded by shallow water; farther towards the land, it forms a low rim around the higher islands, or constitutes, of itself, rather considerable islands; still farther on, in the outer parts of the fjords, it may be observed along their sides. This coast plain generally rises towards the land. The height is varying; probably one hundred meters may be the uppermost limit. This feature in the geography of our country has previously been noted by the author, and by other

observers, so far as regards portions of the coast, but the observations have not before been brought together as a unit, and viewed as a general feature. The annexed little map (1:400,000) shows one of the coast islands to the south of Bryan, encircled by many other smaller islands and skerries (Fig 2). The coast plain is made black, and the parts rising above it are marked with hachures. In the middle of the large island, one will remark a small white cross. If a person were to stand there and look towards the southeast, he would see the landscape represented in the accompanying sketch (Fig 1), in which the mountain Siggen, and some smaller mountains to the southwest of it are seen rising above the coast plain. The next picture (Fig 3) is probably still more characteristic. It gives a view of some islands at a little distance north of the town, Bergen. The island, which looks like a hat, is Alden, 1,500 feet high. The name of the island group with the three small knolls is Varoc. The low tracts, here represented, are not built of loose materials as one might suppose from the appearance, but are almost all carved from solid rock, and hard rock too, viz., crystalline schists of different kinds, dioritic rocks and conglomerates. The region of Bömmeloe, illustrated above, also has a very complex geological structure.

FIG. 2. Region of Bömmeloe.

These are some instances of the mode of occurrence of the remnants of the coast plain. The plain may be traced along our whole western coast from 50° north latitude to the extremest

frontier towards Russia. A map of it will be communicated to the "Year-book of the Geological Survey of Norway for the years 1892–3. Kristiania, 1894."

The coast plain is rather rough and uneven, with small valleys, and often with innumerable small crags. This roughness of the coast plain, which is partly covered by the sea, has produced the myriads of islands, large and small, and the skerries, or

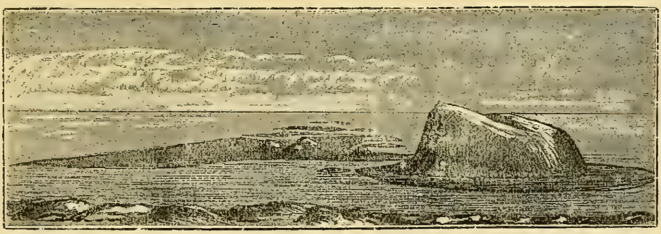

FIG. 3. Mount Alden and the Varoc Islands.

insulated rocks, which are scattered along the greater part of the Norwegian coast. On this coast plain lie the towns of Havanger, Bergen, Tromsoe, and others. Here live hundreds of thousands of people out of our two millions. It is thus seen to be of great importance to our nation. Without it, the whole western coast would be like the bare region east of North Cape, where the coast plain is generally wanting.

The coast plain is a plain of denudation, or a base-level. "It marks a sea-level, to which the land has been reduced by sub-ærial forces." It is glaciated and, in the author's opinion, it has been worked out in periods previous to the glacial period, and in the intervals of that time, when the land was free from ice. The time that has elapsed since the ice-age is too short to be of any importance for the great work performed.

In comparison with the great geographical phenomena here treated, the present strand-lines are small things, though they give evidence that the forces, which made the coast plain, are still working. It has occurred here, as so often elsewhere, that one remarks the small things before the great ones.

HANS REUSCH.

GLACIAL CANONS.

Historical Note.—This paper was presented before the American Association for the Advancement of Science at the Minneapolis meeting, where it was kindly read by Mr. Warren Upham in the absence of the author. A brief abstract was printed in the proceedings of that body for 1883, page 238. Subsequently, Dr. J. E. Hendricks, long editor of *The Analyst*, did the favor of reviewing the mathematical portions, and his suggestions are embodied in a note.

The paper is the fruit of field studies in the Sierra Nevada, mainly in the region about Lake Mono, and of subsequent office work in Salt Lake City, under the direction of I. C. Russell, then of the United States Geological Survey, in 1882 and 1883. The paper was not published because it was recognized that one of the most important phases of ice work (*i. e.*, the work at the bottom of the Bergschrund involved in the formation of cirques and rock basins) was not adequately treated. It was then, as it is now, the opinion of the author that ice work is concentrated and culminates in effectiveness in cirques, whether at the heads of water-carved tributaries (cyms or coombes) or in amphitheatres below ice-falls due to varigradational irregularities in the antecedent water-cut profiles, and that this concentration is proved and the correct analyses of the process suggested by the Bergschrund in the one case and by seracs in the other; but the analysis is difficult, and neither then nor later have opportunities occurred for working it out. Recently this phase of ice work has been taken up by Mr. Willard D. Johnson, who brings to the work a rich fund of observation and an acute and vigorous mind, while at the same time the author finds the promise for the desired opportunity for further study fading away; so it is deemed best to publish in the present form, leaving extension and application to others. It may be observed that, while the treatment

of the subject in this paper is analytic, the work was primarily synthetic and based directly on field observations and inferences in the magnificent field of the southern Sierra.

I.

Glacial cañons are characterized by several peculiar features: 1. They are **U** shaped rather than **V** shaped in cross-profile; 2. Small tributary gorges usually enter at levels considerably above the cañon-bottoms; 3. In longitudinal profile the cañon-bottoms are irregularly terraced—*i. e.*, made up of a series of rude steps of variable form and dimensions,—and some of the terraces are so deeply excavated as to form rock-basins occupied by lakelets; 4. The cañons are sometimes locally expanded into amphitheatres; 5. The cañon-bottom is not always obdurate rock, but may consist of coarse fragmental debris in which individual blocks are as deeply striated and as smoothly polished as are the most solid ledges, though they may rest so insecurely in their positions that a hand can overthrow them; and 6. The volume of glacial debris in moraine and valley deposits is but a small fraction of the cubic content of the cañon from which it was derived.

Of these features the first four suggest that glaciers are most effective engines of erosion, while the last two indicate that glacial erosion is inconsiderable. The source of the apparent discrepance may be sought through analysis of the agencies involved in the development of the four features first enumerated.

II.

Whatever be the physical cause of ice-flow, the motion of a glacier is unquestionably determined by (1) the weight of the ice, (2) the declivity of the channel, (3) the share of potential energy not expended in overcoming internal cohesion, and hence available in producing mass motion, and (4) the friction against bottom and sides of the channel; of which factors the last two (one of which is positive and the other negative) are indeterminate. The united effect of all—*i. e.*, the total sum of potential

energy available in generating movement—may be denominated the *down-stream impulse* of the glacier. Such impulse, in combination with the simple *weight* of ice at any point, constitutes the *intensity* of glacial action at that point.

But, *ceteris paribus*, the measure of rock-grinding is the *friction* between the glacier and its bed. Now such friction is a complex function of the weight and down-stream impulse, and varies with, but probably less rapidly than, their product. The general law of friction, applicable under wide ranges of pressure and velocity, has never, indeed, been clearly formulated; and where the contiguous surfaces are so unlike as rock and ice the friction is scarcely known even in the simplest case.[1] In case of such substances, too, if detached rock-fragments intervene, they will project into the more yielding material and thereby increase the frictional surface; when the slip may either (1) occur in part on each side of the fragments (*i. e.*, the ice may flow over the fragments, while they themselves move at a slower rate over the valley-bottom, as has, indeed, been observed by Niles), or (2) may be confined to the inosculating rock-surfaces. Also, if a continuous sheet of comminuted debris intervene, the movement may be divided between its upper and lower surfaces; and if the intercalated sheet be thick, several planes of slip may exist within it and its own motion become differential. Again, if fragments of large angles and not greatly different diameters project into the ice or lie within a differentially-moving ground moraine, the unequal flow will most rapidly carry forward their summits, initiate rolling, and thus diminish friction (and at the same time, perhaps, produce "fluxion-structure"). It follows that the friction in any given case cannot be even approximately evaluated; and its expression must, therefore, include an indeterminate factor of considerable moment.

But, again, the disposition to attack the glacier-bed is

[1] Tylor found that with a pressure of two pounds to the square inch the co-efficient of friction of ice upon ice was between 0.1 and 0.2, and concluded that glacier motion would be impossible without water to lubricate the bottom. Geol. Mag., Dec. II., Vol., II., 1875, p. 280.

(*ceteris paribus*) measured by the ratio between weight and down-stream impulse; for manifestly, if the weight be in excess, the predominant tendency must ever be to fix and retain in their places all bowlders, pebbles, sandgrains, and smaller particles; when the weight and impulse are as w and v in the diagram (fig. 1) their resultant will tend to retain rather than remove

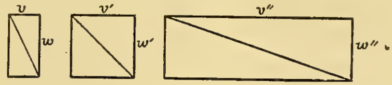

FIG 1.

such fragments, and transportation will be limited to that due to friction and sub-glacial water; when the factors are equal, as are w' and v', their resultant will tend equally to retain and to remove particles, and the effects of friction and flowing water will be counteracted by the greater specific gravity of rock than ice; and when the ratio is as w'' to v'', the disposition will be to overturn and sweep forward all fragments. Also, the weight of ice tends to produce crushing of the rock in a degree probably increasing increasingly with its value. Finally, with increased weight will go increased pressure-liquefaction of the ice, and from this will result the antagonistic effects of reduced friction and augmented transportation. The last two agencies are variable, only very roughly determinate in the ordinary case, and generally of inconsiderable value. They may be thrown together as an unknown factor which, in conjunction with the predominant first agency, constitutes the *effectiveness* of glacial erosion at any point.

The three elements of *intensity*, *friction*, and *effectiveness*, therefore, determine the rate of glacial erosion. To more succinctly express their relations, let—

w=weight of ice at any point;
v=down-stream impluse at any point.
s=rock-surface in contact with any vertical prism of ice;
x=unknown factor in friction term; and
z=unknown factor in effectiveness term.

Then, denoting the three elements by their initials:

$$I = w \times v;$$

$$F = \frac{wvx}{s}\text{; and}$$

$$E = (1 - z)\ \frac{v}{w}\ ^{1}$$

Obviously, these elements are of unlike value in different parts of the cross-section of a glacial valley, and the rate of erosion is hence differential; but since important unknown factors are involved, no reliable expression either for the absolute rate of erosion at any point, or for the ultimate form of the glacial bed, can be directly deduced. The general tendency of glacial action may, however, be learned from separate consideration of the individual tendencies of the several agencies comprehended.

[1] In the above statement, it has been the purpose to eliminate what is thought to be an element of uncertainty in the extension of the customary formula for friction to quantities so great and so peculiarly conditioned as those involved in the movements of great glaciers. It might be simpler also, as Dr. Hendricks points out, to reduce the determinants of glacier motion to those of positive action—viz., (1), the weight of the ice, (2), the declivity of the channel, and (3), the potential energy available in producing mass motion—by excluding the negative determinant, friction. The down-stream impulse might also be represented by $nw\ \sin\theta$, n being an unknown factor depending on molecular force, and hence involving temperature, etc. Then, making x the co-efficent of friction, the equations would become:

$$I = w \times nw\ \sin\theta;$$

$$F = w\ x\ \cos\theta;\text{ and}$$

$$E = (1 - z) \times \frac{v + F}{w\ x\ \cos\theta}.$$

Or, introducing the factor $f\ (v)$ to represent the influence of velocity of flow in determining the friction; the last two equations would become:

$$\mathrm{F} = w\ x\ \cos\theta \times f\ (v);\text{ and}$$

$$\mathrm{E} = (1 - z)\ \frac{v + F}{w\ x\ \cos\theta \times f\ (v)}.$$

It will be observed that this modification of the equations for *intensity*, *friction*, and *efficiency* do not materially affect the discussion, and do not in any way detract from the conclusions reached. The original equations are retained, however, in the opinion that they suggest, if they do not actually present, the more direct and serviceable mode of analysis.

It is a pleasure to acknowledge obligation to Dr. J. E. Hendricks, of Des Moines for working out the expressions in this note (January 25, 1885).

In such consideration let the ice be assumed to occupy a previously-formed gorge of the typical **V** form of water-cut cañóns.

The weight of the ice varies directly with its thickness, and accordingly increases progressively from sides to center of the gorge. The tendency of this factor is hence to continually deepen the cañon and to perpetuate the **V** form.

Three of the four factors into which down-stream impulse may be resolved are of unequal value in different portions of the width of the glacier, and from such inequality the differential flow of ice-streams results; for from sides to center the weight increases uniformly, the available energy increases increasingly, and the friction probably increases less rapidly than the thickness; whence the impulse at the center must ever remain predominant. But if the ice-stream be conceived to consist of a parallel series of longitudinal vertical laminæ (for in the present discussion the vertical variation of flow is immaterial), it is evident that those at the edges will be retarded by the valley-sides, that the medio-lateral laminæ will be equally retarded and accelerated by their unequally flowing neighbors, and that the central lamina will be retarded by the more slowly moving ice on either side; and if the mutual interaction of the various laminæ be considered, that the platted ordinates of flow will form a curved figure, and not a triangle homologous with the cross-section of the gorge (fig. 2). Such indeed is the case of differential ice-flow, as empirically established by Forbes, Agassiz, Tyndall, and other observers; though in the **V** gorge the curve would unquestionably be less flattened than in the **U** gorges within which the measured glaciers lie. On the whole, the disposition of the second factor must be to most energetically attack the valley-bottom, but at the same time to develop concavity of the valley-sides.

Summarizing, it appears that the general tendency of the intensity element is preëminently to deepen the cañon and slightly to transform the **V** to a **U** profile.

Of the factors peculiar to friction, that of indeterminate value doubtless suffers increasing relative diminution as the depth of ice increases, and its platted ordinates (expressed in terms of the valley-profile) will hence form a curve of materially less depth than the triangle formed by the tangents to its extremities (fig. 2). The disposition of the factor is accordingly to widen the gorge and develop the **U** profile.

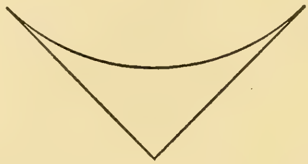

Fig 2.

With the less lateral velocity common to ice-streams will go reduced lateral friction, and hence erosion, in a ratio corresponding to the velocity curve; and for a second reason, therefore, will concavity of the valley-sides be engendered and developed; though the concurrent disposition will be to deepen the gorge.

Whenever concavity of the valley-sides obtains, the contact surface of the vertical prism will become variable. If, now, friction vary approximately with the pressure of the incumbent ice, the consequent erosion will diminish with the increasing slope toward the edges of the glacier; when the disposition will be to deepen the gorge and restore the **V** form; but if the friction vary more nearly with the contact-area, it will increase with the slope, and the resulting erosion will tend to widen the gorge and, in another manner, to restore the **V** profile. Whichever tendency obtains will, however, be secondary and ever subordinate to that of the principal factors of friction. (Subglacial water will at once reduce friction and promote transportation directly and corrasion indirectly; also it will tend, *ceteris paribus*, to form a continuous film between ice and rock reaching upward to 0.92 of the thickness of the glacier, or, if the glacial surface be highly convex, perhaps quite to its margins. On the whole, then, its

influence in any direction must be slight, and its effect may be disregarded).

Combining the several antagonistic factors, it appears uncertain whether the general tendency of the friction element is to widen or deepen the gorge, but certain that it is to develop concavity of the valley sides and the **U** form of cañon.

Since the third and fourth factors in down-stream impulse (available potential energy and friction) are indeterminate, the problem as to the declivity required to render such impulse equal to the weight at any point in a given glacier, or even as to whether such equality ever obtains in nature, cannot be analytically solved; and very few observations showing the relative value of these components have ever been made. Niles,[1] however, found that in the Great Aletsch glacier the ice usually rides upon projecting rugosities and seldom fills the intervening depressions of its bed, and that a bowlder (itself slowly moving) three feet high had formed an inverted trough thirty feet long in the base of the incumbent ice; whence the down-stream impulse must have exceeded ten times the weight. Bonney,[2] also, in the Glacier des Bois and the Glacier d' Argentiere, found all broad and gentle depressions in the glacier beds filled with impressed ice, the narrower depressions not quite filled, the lee of projecting knobs protected for a distance equal to their height, and bowlders lying *in situ* beyond the present terminus of the ice glaciated above and below (showing that here also motion took place along the two planes), all of which phenomena indicate that, in these glaciers, the down-stream impulse is in excess of weight, but in a less degree than in the Great Aletsch. The several observations then demonstrate (1), that down-stream impulse may greatly exceed weight, and (2), that the relation is variable. All were in the upper portions of the valleys where the declivity is great (15° to 20° in the examples described by Bonney), and where the office of the glaciers is preëminently one

[1] Proc. Boston Soc. Nat. Hist., XIX., 1878, 330; Am. Jour. Sci., XVI., 1878, 366.

[2] Geol. Mag., Dec. II., Vol. III., 1876, 197.

of erosion. Now ordinary valleys, whether occupied by streams or glaciers, are of progressively diminishing declivity from source to terminus; ordinary glacial valleys exhibit successive zones of active erosion, feeble erosion, slight deposition, and abundant deposition in passing from their upper reaches to the broader valleys into which they embouch or upon the plains with which they merge; and in such cases the down-stream impulse must wane to practically nothing at the extremities of the glaciers, and must hence greatly fail of the weight. It follows that at some point (or at diverse points) in every extended glacier-course the components weight and impulse are equal at the centre of the glacier.

Since glacier ice but slightly approaches perfect fluidity and the flow of the center is greatly retarded by the sides, the ratio of impulse to weight (and with it the effectiveness) continually and largely increases from center to sides: if the central effectiveness be just zero, that at the sides will nevertheless remain important; if it be minus centrally, it may still be considerable laterally; and however great may be its value at the center, it must have far greater value at the sides. The disposition, then, will ever be to protect the bottom and equally to attack the sides of the valley; and since the down-stream impulse of the several parallel laminæ forms a curve when platted, so will the disposition also be to form concave valley-sides.

Of the unknown factor in the effectiveness term, the first component (rock-crushing) can be but trivial in the ordinary case, while the second (pressure-liquefaction) exercises antagonistic influences. It may, accordingly, be safely neglected.

Collectively, the tendencies of the third element of glacial erosion are (1) to effectually protect the valley-bottom throughout a considerable portion of the glacier course, (2) to develop the **U** form of canon, and (3) to materially increase the relative width of the gorge.

The fifth feature of glacial cañons is explained by the operation of this element, and in turn establishes the importance of the element.

Recapitulating, it appears that of the several elements involved in glacial erosion, the first tends to deepen the gorge and slightly to develop the **U** form, the second to develop the **U** form, and perhaps very slightly to deepen the gorge, while the third and predominant one tends strongly to widen the gorge and protect its bottom, and less strongly to develop the **U** form. It follows that the general tendency of glaciers must be to widen rather than deepen the valleys they occupy, and to transform **V** to **U** cañons. Also, since the typical **U** gorge is just such as would result from temporary occupancy of a **V** gorge by a glacier, while the ordinary ratio of width to depth is less than would obtain were the gorge eroded by glacial action exclusively, it follows again that the characteristic glacial cañons must be only modified stream-cañons.

This conclusion explains, and is equally and directly corroborated by, the first and sixth features of glacial cañons. It also fully warrants the assumption, in the following as in the foregoing discussion, of originally **V** shaped glacier-beds.

III.

As elsewhere shown,[1] corrasion of a stream is a function of its volume, and, *ceteris paribus*, varies with, but less rapidly than that element. In a region of rapid corrasion then, the main stream must (unless the declivity be materially unlike) more rapidly corrade its channel than does its minor tributary; and the tributary cañon must accordingly enter its principal over a rapid or at least a convex curve in longitudinal profile.

If now the main cañon become filled with ice and be transformed from the **V** to the **U** type by its action, the distal extremity of the tributary will be cut off and the original stream-formed declivity replaced by the precipitous side-wall of the normal glacier valley (fig. 3); and this result will follow whether the tributary be filled with or free from ice, provided corrasion

[1] "The Formation of River Terraces" (recently published in Eleventh Annual Report U. S. Geological Survey, 1891, pp. 259–272).

at the cañon-mouth be not relatively increased in a considerable degree.

It follows that the second feature of the typical glacial cañons may naturally result from temporary occupation of water-cut cañons by ice, and that it does not necessarily argue profound glacial erosion.

IV.

In obedience to the law of varigradation,[1] all and particularly smaller streams tend to depart in a minor degree from uniform gradient, and to develop in their channels a longitudinal profile

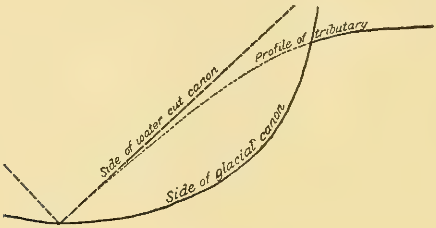

FIG. 3.

of slightly variable declivity; this law finding expression in the alternating pools and rapids of mountain brooks and in the always perceptible and often conspicuous alternations of greater and less declivity in the courses of water-cut cañons.

If now an otherwise uniform **V** cañon of irregular gradient become occupied by a glacier, the flow, varying as it does with the declivity, will become unequal and the ice will tend to accumulate on the planes of low declivity until it approaches a uniform surface slope; when the weight of ice at different points in the medial or other longitudinal plane of the glacier will become variable, and will reach a maximum over the greatest depression (fig. 4). With such increased weight will go (*a*) direct increase of intensity with the augmentation of its principal factor, (*b*) indirect increase of intensity in virtue of the office of weight as a function of the down-stream impulse, and (*c*) direct diminution

[1] Op. cit, p. 295.

of intensity in consequence of the absolutely reduced down-stream impulse; also (*d*) material increase of friction with the augmentation of its principal factor, and (*e*) less material diminution of friction in consequence of the reduced impulse; and finally (*f*), direct diminution of effectiveness with the absolute decrease of impulse, (*g*) indirect diminution of effectiveness in consequence of the relative decrease of the same factor, and (*h*) direct but slight increase of effectiveness in virtue of the operation of the obscure factor of rock-crushing and pressure-liquefaction; or, summarily, increase in intensity, slight increase in friction, and decrease in effectiveness.

Now, in view of the obscure and antagonistic though inter-

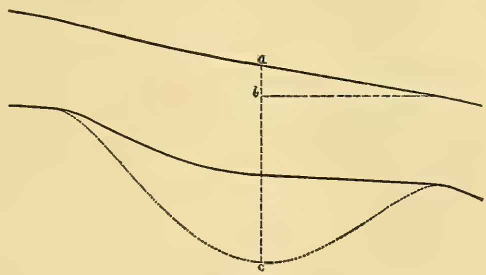

Fig. 4.

dependent relations involved, it is evident that without exhaustive quantitative investigation (impossible in the present absence of knowledge concerning friction between ice and other substances) it cannot be determined in the ordinary case whether the disposition will be to erode the more rapidly where weight increases at the expense of declivity, or where the reverse occurs; but it appears quite certain that where the surface declivity materially exceeds that at the base, and where, accordingly, the impulse is not reduced proportionally to the declivity of the channel, erosion must progressively increase with the weight. If so, the tendency of glaciers must be to cumulatively intensify the irregularities in gradient normal to water-cut cañons.

But corrasion and transportation in any part of a glacier-bed are limited directly by flow of ice and indirectly by coincident

flow of subglacial water. Now, loss of effectiveness through absolute and relative increase of weight must eventually become potent in retarding direct excavation of the depression; also, whenever the depression becomes so considerable as to possess reverse slope toward its distal extremity, gravity will no longer enhance, but instead oppose, direct transportation of detritus; again, with increased depth of depression will go increased cross-section and concomitant and material diminution of velocity and eroding capacity in the ice-stream; and finally, the longitudinal perimeter of the depression must continually increase until the fricton along it approaches and ultimately equals the shearing strength of the ice along its chord, whence the movement of the basal segment must concurrently diminish and gradually cease. In like manner, when the normal slope becomes reversed, gravity will oppose and not enhance transportation by subglacial water; also, as the reverse slope increases, the flow of such water will become sluggish and its capacity diminished; and finally, when the depth of depression below its distal rim reaches 0.92 of the maximum depth of ice (or when *b-c* equals 0.92 *a-c*, fig. 4), the subglacial water will assume static equilibrium, the incumbent ice will suffer flotation, and both corrasion and transportation will practically cease. Thus the excavation of depressions by direct ice-action has a definite though indeterminate limit, and can probably never exceed a moderate fraction of the depth of the ice; and thus also indirect glacial erosion in depressions through the coöperation of subglacial water alike in corrasion and transportation will remain effective until the depth of excavation approaches the thickness of the incumbent ice; whence, in the general case, the measure of maximum excavation of rock-basins is a large fraction of the depth of the glacier.

(Evidently embouchures of valleys, zones of abrupt diminution in declivity, points at which for any reason glaciers terminate for considerable periods, broad cross-valleys beneath continuous ice-sheets, and all localities where the surface slope of the ice materially exceeds the slope of its base, will form as definite loci of active excavation as do the ordinary planes of

low declivity developed by varigradation; and at such localities, accordingly, glacial lakes, the submerged rock-basins characteristic of fjords, and other evidences of energetic ice-action remain after the melting of the ice.)

It follows, then, that the third feature of glacial cañons may result simply from glacial occupation of water-cut cañons; and since in the common mountain region from which the glaciers have completely disappeared the irregularities of gradient peculiar to such cañons are not greatly intensified, while glaciated rock-basins are comparatively rare and of slight depth, it equally follows that the occupation was only temporary, and the sum of glacial erosion relatively inconsiderable.

V.

The immediate effect of the origin of a tributary cañon in a developing drainage-system is the exposure of a greater length of canon-wall to degradation; from which effect in turn results (under certain conditions of homogeneity of terrane and uniformity of altitude in the region, and hence of repeated bifurcation and wide dispersal of the branches of the nascent tributary) the formation of an amphitheatre opening into the main cañon. Then, after the considerable development of the tributary, its disposition will be, as shown by Warren,[1] to dam the main stream and diminish the declivity above its confluence; whereby lateral corrasion will increase at the expense of vertical corrasion there. Thus, by increased lateral corrasion the amphitheatre will ever tend to expand within certain limits immaterial in this discussion. Such amphitheatres, exhibiting the tortuous outlines characteristic of fluvial erosion, have been well illustrated by Dutton,[2] and are common features in many mountain regions.

If now a glacier enter and fill such an amphitheatre, its rate of flow and similarly its rate of erosion on the given area will be

[1] "An Essay Concerning Important Physical Features Exhibited in the Valley of the Minnesota River," 1874–7; and elsewhere.

[2] "Tertiary History of the Grand Cañon District," 1882, Chapter IX, and maps accompanying.

reduced by increase of width and depth; though if (as is probable) erosion varies more nearly with the weight than the velocity, its amount will increase absolutely, and the expanded valley will tend in a stronger degree than that measured by the ratio of the inverse volumes to assume the general form characteristic of contracted glacial gorges. As in the contracted gorge, too, lateral effectiveness will remain predominant; but the effective energy of the glacier will be mainly concentrated upon the obstructive angles, spurs, and cusps of the irregular water-carved walls, and the removal of these and the rounding out of the amphitheatre will be in the first work of the glacier. Again, the partial rigidity of the ice-mass will lead to culmination of pressure about the distal extremity of the amphitheatre, and to consequent extension of its boundaries beyond the confluence of the tributary by which its water-fashioned prototype was originated.

It follows that glaciated amphitheatres may be merely water-carved valley expansions modified by temporary ice-action into regularity of contour (as are, for instance, those of the Faeröe Islands[1]), and that they do not necessarily argue profound glacial erosion.

VI.

Summarizing the chief effects of the several agencies involved in the development or the characteristic features of glacial cañons, it appears that temporary occupancy of a typical water-cut cañon by glacier ice will (1) increase the width, (2) change the **V** to a **U** cross-profile, (3) cut off the terminal portions of tributary cañons, and thus relatively elevate their embouchures, (4) intensify certain irregularities of gradient in the cañon-bottom, (5) excavate rock-basins, (6) develop amphitheatres, and, in general, transform such cañon into an equally typical glacial cañon. It follows that these features do not necessarily imply extensive glacial excavation or indicate that glaciers are superlatively energetic engines of erosion.

W J McGee.

[1] J. Geikie, "Geology of the Faeröe Islands," Trans. Roy. Soc., Edin., 1882.

FOSSIL PLANTS AS AN AID TO GEOLOGY.

Paleobotany, together with all the other branches of paleontology, admits of subdivision into two lines, or fields of study—the biological and the geological—depending upon the prominence that is given to the one or the other of these subjects. The biological study concerns itself with the evolution of the vegetable kingdom, that is, with the tracing of the lines of descent through which the living flora has been developed. The geological side of paleobotany has two phases, one of which concerns itself with the associations, time relations, and distribution of the plant forms which constitute the successive floras of the geological ages and form an important element in the life history of the earth, while the other is concerned principally with the use of fossil plants as stratigraphic marks, but also with any aid that may be rendered in elucidating the many intricate problems which geology presents. The latter, or geological aspect, is almost exclusively the phase of the subject to which the present paper is devoted.

Before passing to an elaboration of the claims that paleobotany may have as an aid to geology, it may not be out of place to call attention to the fact that the successful use of fossils as stratigraphic marks is, or at least may be, entirely independent of their correct biological interpretation. It makes not the slightest difference to the stratigraphic geologist whether the fossils upon which he most relies are named at all, so long as their horizon is known and they are clearly defined and capable of recognition under any and all conditions. They might almost as well be referred to by number as by name, although, of course, every paleontologist seeks to interpret to the best of his knowledge the fossils that he studies. He may, probably often does, make mistakes in his attempts to

understand them, but from the very nature of the case this must be so. They must all be studied in the light of recent forms, which, in the case of wholly extinct groups, is a matter of great difficulty.

On the other hand, to the historical geologist who makes use of fossils in unravelling the succession of geological events, the correct biological identification is of the greatest importance, for upon this rests his interpretation of the succession of faunas and floras that have inhabited the globe. These principles are tersely stated by Dr. C. A. White in one of his essays on "The Relation of Biology to Geological Investigation."[1] He says: "If fossils were to be treated only as mere tokens of the respective formations in which they are found, their biological classification would be a matter of little consequence, but their broad signification in historical geology, as well as in systematic biology, renders it necessary that they should be classified as nearly as possible in the same manner that living animals and plants are classified."

PRINCIPLES OF PALEOBOTANY.

There are certain broad, fundamental principles upon which the science of paleobotany rests. Some of these are so simple as to be almost axiomatic, while others are less evident and have only recently been recognized. It has been disregard of these principles that, in the past, has often brought paleobotany into disrepute. Each of the departments upon which geology calls for aid has to acknowledge limitations, and so paleobotany has bounds beyond which it can not be legitimately asked to go. But it is confidently predicted that when the evidence has been sifted, and the limitations, as well as the just claims, have been properly adjusted, the evidence derived from fossil plants will be as reliable as that supplied by other branches of paleontology.

One of the most important principles has been admirably

[1] Ann. Rept. U. S. National Museum, 1892, p. 261.

expressed by Professor Ward.[1] It is that "Great types of vegetation are characteristic of great epochs of geology, and it is impossible for the types of one epoch to occur in another." For example, the presence of a dicotyledonous leaf, no matter how fragmentary, is proof positive that the stratum containing it is Mesozoic or younger. It can not possibly be older. Again, the presence of a single scar of Lepidodendron or Sigillaria, when not in redeposited strata, is just as strong evidence that they came from a Paleozoic horizon, since not a single specimen has ever been found later than the Permian.

The application of this principle is often of the greatest aid in geology, for, as frequently happens, the strata of a region have been much displaced and distorted, and it is no uncommon thing to find Paleozoic rocks occupying the positions that should seemingly, normally be taken by Cretaceous or Tertiary strata. The stratigraphy may be so exceedingly complicated as to render it quite impossible to distinguish Paleozoic from Mesozoic strata. Nor can petrography be always depended upon to supply distinguishing marks. In such cases, which are by no means purely hypothetical, a single fossil plant may serve to set at rest all possibility of dispute.

An example of this kind is furnished by the well-known case of the beds of Chardonet in France, "studied by Élie de Beaumont in 1828 and positively referred to the Mesozoic, but in which fossil plants of the genera Calamites, Sigillaria and Lepidodendron were identified by Brongniart."[2] At that time the principle under discussion had not been recognized and Brongniart was "inclined to admit" that these genera might have occurred in the Mesozoic, although long before his death he recognized it and realized that the genera indicated beyond question a Paleozoic age.

Another important principle, bearing upon the limitations of paleobotany, is what has been called the law of homotaxis.

[1] Principles and Methods of Geologic Correlation by means of Fossil Plants. Am. Geol., Vol. IX., 1892, p. 36.

[2] Ward, l. c.

As long ago as 1853 Pictet, in his then celebrated *Traité de Paléontologie*, presented a number of general principles, among them being one, the so-called eighth law, which bears directly upon the present question. It is as follows: "Contemporaneous deposits, or those formed at the same epoch, contain identical fossils. Conversely: deposits which contain identical fossils are contemporaneous." This was modified by Schimper,[1] the celebrated French paleobotanist, who added that deposits "formed at the same epoch, contain floras, if not completely identical, at least homologous, and consequently deposits that contain identical or homologous floras are contemporaneous." But Huxley appears to have been the first (1862) to formulate clearly the objections to this law. He pointed out that while the succession of life in widely separated localities may be shown to have been similar, it by no means follows that the identical elements in these widely separated localities were strictly contemporaneous. To this he applied the term *homotaxis*, which implies that the plants and animals of widely separated places may have had practically the same process of development or succession, yet when the element of time is considered they may have been far from identical. As an example it may be mentioned that the most abundant and typical genus of plants in the Carboniferous rocks of Australia and Tasmania is Glossopteris, a genus which is not represented in rocks of similar age in Europe, but occurs in Upper Mesozoic beds of that region.

This, it will be readily understood, applies to localities widely separated, as for example between continents that are not intimately connected, or that are now and have been for a long geological period separated by insurmountable barriers to immigration, such as oceans and mountain chains. The plants originating within a given area or the ones inhabiting a locality adapt themselves to the environment, and these can only extend their distribution readily to areas in which the conditions are similar. Hence if the particular locality in which a species has been developed is separated from other areas, perhaps as well suited

[1] Traité de Pal. Vég., Vol. I., 1869, p. 100.

to its growth, by a natural barrier such as a lofty, unbroken mountain chain or a broad expanse of water, the chances are against the species finding its way quickly to the remote areas. As an example of this may be cited the flora of the Hawaiian Islands. This flora, exclusive of the species introduced since the discovery of the Islands by Cooke in 1779, embraces 860 species of phanerogams and vascular cryptogams. Of this number no less than 653, or 75.93 per cent. are endemic or peculiar to the Islands. On account of the vast expanse of the Pacific by which the Hawaiian Islands are separated from the nearest land, the flora has been unable to extend its distribution.

It is but reasonable to suppose that similar conditions existed in past geologic ages, but by the obliteration of barriers, such as the shallowing of the water or emergence of direct land connection, the plants may have been enabled to invade new territory, and thus extend from area to area or from continent to continent. If now an examination is made of the remains of vegetation in two or several widely separated areas, the succession will be found to have been the same, but they may not have been strictly contemporaneous.

What now is the deduction to be made since the formulation of this principle regarding the value of paleontologic evidence? Does it immediately follow that all correlations based upon similarity of fossil remains fall to the ground? By no means. It has simply introduced an additional element of caution into the problem of correlation between widely separated areas. And even here it has been, and must continue to be, of the greatest importance, for, as Professor Ward has well said,[1] "What we possess is the general fact that a similar flora once existed in two parts of the world very widely separated, and until some other facts are discovered which complicate and vitiate such a conclusion, it is both safe and useful for the geologist to regard the two deposits as belonging to the same geologic age. There are certain limitations within which this must be true, and when these limitations are recognized the paleontologist may as safely

[1] loc. cit. p. 47.

draw his conclusions as he could before the law of homotaxis had been formulated."

Thus, while admitting the possibility of homotaxial relations existing between the floras of widely separated areas, certain correlations, on the basis of simultaneity, of extensive series of beds in different countries, have stood the test of time. On this subject Sir William Dawson has given important evidence.[1] He says: "I desire, however, under this head, to affirm my conviction that, with reference to the Erian and Carboniferous floras of North America and Europe, the doctrine of 'homotaxis,' as distinct from actual contemporaneity, has no place. The succession of formations in the Palæozoic period evidences a similar series of physical phenomena on the grandest scale throughout the northern hemisphere. The succession of marine animals implies the continuity of the sea-bottoms on which they lived. The headquarters of the Erian flora in North America and Europe must have been in connected or adjoining areas in the North Atlantic. The similarity of the Carboniferous flora on the two sides of the Atlantic, and the great number of identical species, proves a still closer connection in that period. These coincidences are too extensive and too frequently repeated to be the result of any accident of similar sequence at different times, and this more especially as they extend to the more minute differences in the features of each period, as, for instance, the floras of the Lower and Upper Devonian, and Lower, Middle, and Upper Carboniferous."

USE OF FOSSIL PLANTS IN RESTRICTED AREAS.

Turning now from the correlation of strata in widely separated localities, we come to that part of the field in which geology is likely to receive its most valuable aid from paleobotany, viz.: the identification of horizons and their correlation within restricted areas. While the phase of the subject which has just been discussed may be of much importance when the final volume of the geology of the world comes to be written, it can

[1] Geological History of Plants, p. 262.

never, if we are to judge by the recent trend of attempts at wide-spread correlation, hold the position of importance that correlation within circumscribed areas does. The minor subdivisions of the geological time-standard established for Europe, for example, is found to be of only limited application in North America, and attempts to bring them into complete harmony are little short of wasted energy. But with limited or natural areas the case is far different.

Organic remains are unquestionably of first importance in identifying formations. The study of the mineral composition and lithological characteristics of formations must be abandoned as the sole means necessary for their identification. Recourse must be had to the fossils to set the stratigraphist aright, for as Professor J. W. Judd has said,[1] "We still regard fossils as the 'medals of creation,' and certain types of life we take to be as truly characteristic of definite periods as the coins which bear the image and superscription of a Roman emperor or of a Saxon king." Of the various kinds of such remains fossil plants occupy relatively as important a position as those afforded by most of the other biological groups.

It is by no means uncommon to find that fossil plants are almost the only organic remains present in a formation, but if they are not, the evidence they afford, when properly interpreted, confirms that obtained from other groups of organic life, as the following examples will show.

As an illustration of the first mentioned condition, viz.: that in which plants only are present in numbers sufficient to entitle them to exclusive consideration, the Dakota group offers an exceptionally fine example. This formation is four or five hundred miles wide, more than a thousand miles long and of considerable thickness, yet not a single vertebrate fossil, and hardly ten species of invertebrates have thus far been detected throughout its vast extent. The Dakota flora, however, is one of the most extensive and thoroughly known fossil floras. According to Lesquereux[2]

[1] Nature, Vol. XXXVII., 1888, p. 426.

[2] Flora of the Dakota Group, p. 14.

460 species have been described from this formation, of which number no less than 394 are peculiar, that is, have never yet been found outside of it. A very large number of these plants are so characteristic that their discovery in strata of unknown age would settle at once their reference to this horizon. An illustration of this is just at hand. A single dicotyledonous leaf was some time ago described,[1] under the name of *Sterculia Drakei*, from the upper sandstone of the Tucumcari beds near Big Tucumcari Mountain, New Mexico. This plant has lately[2] been referred to as the only dicotyledon known from the Trinity beds of the Comanche series, a reference that is, so far as we know, highly improbable, for Fontaine, in his descriptions of all of the plants now known from these beds[3] finds no trace of dicotyledons. A glance at the figure of the Tucumcari plant suffices to show that it is *Sterculia Snowii*, a well-known, very abundant, and characteristic plant of the Dakota group. This leaf, together with what is now known of the position of the rocks containing it, is amply sufficient to settle the age of this portion of the Tucumcari sandstone, a conclusion agreeing perfectly with the results several times set forth by Professor R. T. Hill from stratigraphic and paleontological grounds. The Potomac formation furnishes a parallel example. This series of beds, extending in almost unbroken line from New Jersey to Alabama, contains a known flora of 737 species, over 80 per cent. of which are peculiar.

An example of the complete accord existing between fossil plants and other organic remains in determining age is offered by the Trinity Division of the Comanche Series of Texas, the flora of which, so far as known, has recently been worked out by Fontaine.[4] The particular beds in this series, from which the plants came, have been named the Glen Rose or alternating strata, by Professor R. T. Hill, and their age determined by marine invertebrates, as Neocomian or basal Cretaceous. The flora consists of twenty-

[1] Geol. Survey of Texas, 3d Ann. Rept., 1891, p. 210.

[2] Am. Geol., Vol. XII., 1893, p. 327.

[3] Proc. U. S. National Museum, Vol. XVI., 1893, p. 261–282.

Op. cit., p. 281.

three species of plants characteristic of the lower Cretaceous, and appears to find its closest resemblance in the older portion of the lower Potomac. Professor Fontaine's results are summed up as follows: "The Glen Rose or alternating strata, in which the fossil plants are found, contain an abundant marine fauna, from the evidence of which Professor Hill had concluded that its age was Neocomian or basal Cretaceous. No fossil plants had hitherto been found in the Comanche series, and the evidence of its age was derived wholly from the animal remains. The discovery of plants in it was, then, of special importance, for it enabled us to compare the evidence of the plant-life with that of the animal life. It is interesting to find so close an agreement. This agreement adds one more proof of the value of fossil floras in fixing the age of the strata in which they are found."

The age of the strata exposed at Gay Head, on the western end of Martha's Vineyard, has been the subject of discussion and speculation by geologists for nearly or quite a hundred years, and the question has only recently been settled. In general the strata have been correlated with the similarly appearing strata of Alum Bay in the Isle of Wight, the position of which is fixed as middle Eocene. It is true that certain Cretaceous shells had been found, but they were not in place, and so intermingled with recent forms, that it was concluded that the age could hardly be other than lower or middle Tertiary. As late as 1889 Professor N. S. Shaler[1] decided, upon purely stratigraphic grounds, that "this part of the Tertiary series is certainly of later Miocene or Pliocene age.

In 1890 Mr. David White visited Martha's Vineyard, and was fortunate enough to find and collect a considerable series of fossil plants from the strata in question. The results of this study[2] showed beyond all doubt that they were of Cretaceous age, many being identical with the plants of the Amboy clays of New Jersey. "The Gay Head flora," Mr. White concludes, "indi-

[1] Seventh Annual Report U. S. Geol. Survey, 1885–6, p. 332.

[2] Cf. Am. Jour. Sci., Vol. XXXIX., 1890, pp. 93–101.

cates an age certainly Cretaceous, and probably middle Cretaceous."

Here, then, is an example of the value of a few fossil plants in determining the age of a series of beds where a hundred years of study from the stratigraphic side had failed to accomplish conclusive results.

The flora of the so-called Laramie beds of the Rocky Mountain region has also been the subject of much discussion and controversy. By certain of the older writers it was referred to the Tertiary, by others to the Upper Cretaceous. Recent investigation has shown, however, that several distinct horizons were embraced in what has been known as the Laramie. The tendency appears to be to restrict the term "Laramie," at least in the Colorado district, to the lower or older beds, and accordingly the Post Laramie beds have been differentiated and given independent names. As fossil plants are the most abundant organic remains present in this series of strata, their bearing on the question of the age and differentiation of the beds is important. No dependence can be placed on the earlier determinations of the distribution of the plants, for the reason that the different horizons had not then been distinguished, and the plants are often recorded from a locality at which several of the horizons are present and plant-bearing. It has been necessary to go over all the original material and determine by studying the matrix, and by duplicate collections, the actual horizon to which they belong. In this way the status of 285 species now known to occur in these beds has been settled. In Colorado and New Mexico, the only area in which the interrelations have yet been worked out, it appears that there is a flora of 165 species, of which number 62 belong to the true Laramie and 103 to the Denver beds, and with only 7 species common to both. This proves beyond question that the Laramie and Denver beds are distinct, and that they possess, in certain clearly defined species of fossil plants, readily recognizable stratigraphic marks.

The deductions made from this datum point, viz.: the thorough study of the flora of the Colorado Laramie and allied

formations, are already important. Of these two or three examples may be cited.

The Post-Laramie beds of Middle Park, Colorado, have been made the subject of an investigation by Mr. Whitman Cross. After reviewing historically the opinions of various writers as to the age of these beds, he discusses exhaustively the results of recent work in this field. He reviews the fossil flora at length, correcting many obvious errors of locality and horizon into which the early collections had fallen, and finally presents a revised list of the plants known certainly to have come from the Middle Park beds. In the light of the revisions of the Laramie and Denver floras, nearly 75 per cent. of the species enumerated in this list are found to be common to the Denver beds. The complete agreement of the paleobotanical with the other geological evidences is well shown in conclusions of Mr. Cross, which are as follows: "The unconformable relationships, lithological constitution, and fossil flora all indicate the equivalence of the Middle Park and Denver beds. No evidence seems to indicate any other correlation."[1]

The Laramie and Post-Laramie beds of Montana have been studied by Mr. W. H. Weed.[2] His paper gives an account of a series of beds heretofore embraced within the Laramie, and covering the greater portion of the State of Montana east of the Rocky Mountains. It is shown stratigraphically that the thickness of some 13,000 feet of strata belong to three formations: the Laramie, the overlying Livingston, and the higher Fort Union beds.

Fossil plants occur in all three of these formations, and from their study it is made clear that the Livingston beds occupy the same position in Montana, with reference to the Laramie, as do the Denver beds in Colorado. Of 22 species of plants found in the Livingston beds no less than 17 are found either exclusively in the Denver, or have their greatest development in this formation.

[1] Proc. Colorado Scientific Soc., 1892, p. 26 of reprint.

[2] Bull. U. S. Geol. Survey, No. 105.

Large numbers of huge vertebrate remains, only known from "The Laramie of Wyoming," fortunately have fragments of fossil plants adhering to them, from the study of which important light will be thrown on the age of the beds in which they are contained.

Along the Missouri river in the vicinity of Great Falls, Montana, there is exposed a considerable thickness of mainly brown, sandstone rocks. They have been eroded by the river into more or less of a cañon, and are the material in which the falls have been developed. From their lithologic appearance, but mainly upon stratigraphic grounds, these rocks have been referred by geologists to the Dakota group. On going down the river they disappear under the Fort Benton shales, and are consequently in the stratigraphic position of the Dakota, but the recent discovery of plant-beds near Great Falls has shown the impossibility of such reference. The plants are typically lower Cretaceous, and have been positively identified by Newberry with the Kootanie of Canada. By this a part at least of the so-called Dakota goes to the lowest Cretaceous.

In a similar way a part of the supposed Dakota of the Black Hills has been shown by Professor Ward,[1] purely on paleobotanical evidence, to belong to the lower Cretaceous.

The Foreman beds in the Taylorville region, Plumas county, California, were determined to be of Rhætic age from the fossil plants, a determination agreeing perfectly with the stratigraphy.[2]

The copper mines near Abiquiu, New Mexico, were identified as Triassic by the plants found in and about the roof of the openings.[3]

The employment of fossil plants in practical mining exploitation is well shown by the results obtained by Grand' Eury and Zeiller in Southern France.

In the Department of Gard the mining of coal is one of

[1] Journal of Geology, Vol. II., No. 3, pp. 250–266.

[2] Diller: Bull. Geol. Soc. Am., Vol. 3, p. 373.

[3] Fontaine & Knowlton: Proc. U. S. Nat. Mus., Vol. XIII., 1890, p. 282–285. Newberry: Rep. Expl. Ex. in 1859 under Macomb. Wash., 1876, p. 140.

the most important industries. In this district there are a number of veins of workable coal which have been formed at different epochs. These veins are separated from each other by barren strata of varying thickness, and are always accompanied by certain characteristic plants, especially ferns and allied forms.

In the valley of the Grand' Combe there are a number of coal openings, among which may be more especially distinguished those of the Sainte Barbe and Grand' Combe. M. Zeiller, the engineer-in-chief of the mines, from a study of the fossil plants which accompany the two layers, determined that the first deposit, viz.: that of Sainte Barbe, was older than the other. With this knowledge in his possession, M. Zeiller did not hesitate to counsel the company that by sinking a shaft at a place called Richard, just outside of the valley of the Grand' Combe, they would reach a new seam of coal corresponding to the Sainte Barbe. The shaft was sunk for 400 meters, but as only barren strata were encountered it was abandoned, and it was reserved for Grand' Eury to prove the correctness of Zeiller's prediction.

Grand' Eury, in a general study of the coal basin of Gard by means of fossil plants, determined that the coal of Sainte Barbe was deposited at the same epoch as that of Bessèges, from the fact that the same plants occurred at both localities. In the same manner he proved that the coal of Grand' Combe was of the same age as that of Gangières, but he also found that between the beds of Bessèges and Gangières there was a barren series of strata approximating 600 meters in thickness. It therefore became evident that the shaft at Richard had been abandoned too hastily, and work was again prosecuted, and at a depth of 731 meters the vein of coal, 4.80 meters thick, corresponding to the Sainte Barbe, was reached.

STUDY OF FOSSIL PLANTS BY MEANS OF INTERNAL STRUCTURE.

By far the larger proportion of fossil plants are preserved in the form of impressions or casts of leaves, fruits, stems, etc., only comparatively few having the internal structure so preserved as

to admit of their study under the microscope. The parts usually exhibiting internal structure are stems, branches, roots, and other normally hard organs, yet in exceptional cases every part of the plant, including the leaves, buds, and flowers, are so perfectly preserved that they may be as successfully studied as though living. An example of this kind is afforded by the Carboniferous groups of Cordaites, found in a state of silicification in central France.

Plants that are so preserved as to retain their internal structure, admit of closer study and characterization than is usually attained for other plant organs. So valuable is this method that Professor W. C. Williamson, the distinguished English paleobotanist, was led to say[1] "that no determinations respecting fossil plants can have much absolute value save such as rest upon internal organization ; that is the basis upon which all scientific recent botany rests, and no mere external appearances can outweigh the positive testimony of organization in fossil types." Therefore, when it is possible to obtain plant remains with the internal structure preserved, it may be safely set down that they will afford valuable and reliable data for stratigraphic identification.

The study of the internal structure of fossil plants is yet young in North America, and while a broad field remains for future investigation, enough has alreadv been accomplished to show its value. A few examples may be cited :

In 1888, *Araucarioxylon Arizonicum* was described from the Trias (Shinarump group of Powell) of New Mexico. The same species has been found characteristic of the Trias of North Carolina[2] and of the copper mines near Abiquiu, New Mexico.[3]

In his paper on the geology of Skunnemunk Mountain, Orange county, New York,[4] Professor C. S. Prosser relies upon

[1] On the Organization of the Fossil Plants of the Coal Measures. Roy. Soc., London. Phil. Trans.. Vol. 161; 1871; p. 492.

[2] RUSSELL : The Newark System, p. 29.

[3] FONTAINE and KNOWLTON : Notes on Triassic plants from New Mexico. Prcc. U. S. Nat. Mus., Vol. XIII., 1890, pp 281–285.

[4] Trans. N. Y. Academy Science, Vol. XI., June, 1892.

the fossil plants, especially *Nematophyton crassum* known from the study of its internal structure, to prove the Middle Devonian age of that part of the geological section.

Certain well-defined species of fossil wood are characteristic of particular horizons, as for example *Cordaites Ouangondianus* (Dn.) Göpp., which is confined to the Middle Erian (Devonian); *C. Halli* (Dn.) Kn., and *C. Newberryi* (Dn.) Kn., are confined to the Hamilton Group; *Dadoxylon annulatum* Dn., found only in the middle coal-measures, etc.

SUBSIDIARY USE OF FOSSIL PLANTS.

Among the many relatively subsidiary problems connected with the application of paleobotany to geology, the use of fossil plants as tests of past climate occupies an important place. Plants are unable to migrate like animals when the temperature of their habitat becomes unfavorable, and they must either give way, or adapt themselves gradually to the changed conditions of environment. Hence, fossil plants have always been accorded first place as indices of past climates. "They are," as Dr. Asa Gray has said, "the thermometers of the ages, by which climatic extremes and climate in general through long periods are best measured." [1]

The wide geographical distribution and similarity of appearance of Paleozoic plants, especially coal-measure plants, argues beyond question a uniformity of climatic conditions. The absence of rings of growth in the Carboniferous conifers shows, as long ago pointed out by Witham, that the seasons, if such they could have been called, were either absent or not abrupt, and it is not until the Trias is reached that the clearly defined rings of growth bear indisputable evidence of the existence of seasons.

"Heer, as a result of his examination of the Swiss Tertiary plant-beds, is led to the interesting conclusion that in certain cases it is possible to detect the regular recurrence of seasons by the constant association in the same strata of fruits or leaves

[1] The Nation, No. 742, September 18, 1879.

of plants whose living representatives are known to agree closely in their period of vegetation."[1]

Fossil plants may also, in certain cases, be used to indicate the character of the water in which the deposits were laid down. Thus, the finding of an abundance of marine diatoms in an undisturbed formation is proof that they were deposited in salt water, and the finding of diatoms only known in connection with hot springs is equal proof of former thermal activity. As an example of the last may be mentioned the finding of a large number of species of diatoms in beds of infusorial earth in Utah that are now found living in a hot spring (temperature 163° F.) in Pueblo Valley, Humbolt County, Nevada, showing that the fossil specimens must have been accumulated in a hot lake of about the same temperature.[2]

It is quite commonly argued that during Carboniferous time there was present such a large amount of carbon-dioxide that it produced a thick veil, hiding or at least largely obscuring the direct sunlight. This extreme view is not wholly sustained by fossil plants, for the presence of strongly developed palisade parenchyma in certain leaves, as in Cordaites and many ferns, which can only be formed in direct sunlight, shows conclusively that there must have been at least gleams of sunlight penetrating the so-called veil.

LEGITIMATE FIELD OF PALEOBOTANY.

Before leaving the subject it may be well to point out some of the responsibilities resting with the geologist who would avail himself of paleobotanical aid in the determination of horizons. In the first place, if it is worth while to ask an opinion of the paleobotanist, it is surely worth while for the geologist to spend time enough when making the collection he would submit, to procure at least a fair representation of the fossil flora of that horizon. To expect the paleobotanist to unravel a stratigraphic problem that has perhaps puzzled the trained stratigrapher and

[1] A. C. Seward. Fossil Plants as Tests of Climate, p. 20.

[2] Am. Journ. Sci., 3d ser., Vol. IV., 1872, p. 148.

petrographer, by the examination of a mere handful of specimens gathered hastily as a "last thought," is asking too much! There is a limit to what can legitimately be expected of paleobotany, just as there is a limit to all knowledge.

Again, it has frequently been a practice among geologists to submit a collection of fossil plants without indication of the specific information desired or even of the locality whence the specimens came. This is done presumably with the idea that the paleobotanist, being unembarrased with previous information, would be the better able to give an unbiased opinion. This again is wrong, and under such circumstances the paleobotanist would be amply justified in declining to express an opinion. Unless he can be placed in possession of all the information known to the geologist, or, what is better, have an opportunity of examining the relations of the horizons himself, he should hesitate before passing judgment. Of course, as pointed out under the discussion of principles, certain broad conclusions may be made instantly, such as the presence of dicotyledons proving an upper Mesozoic age, or Lepidodendra and Sigillaria arguing a Paleozoic age. These, however, are not usually the problems presented, but close questions of age, as, for example, the Miocene or Pliocene age of the auriferous gravels of California.

It has been argued by many, especially botanists and geologists, that it is undesirable to give names to fragmentary and seemingly indeterminable plant remains. When a definite name is given it implies, it is argued, a more exact knowledge than is often times possessed; a view that in many cases is undoubtedly correct. But the name is given, when the fossil cannot be made out satisfactorily, for purely practical reasons. It embodies, or should, the best possible judgment as to its nature and systematic position, and serves as a convenient basis of future mention of it without tedious circumlocution.

The foregoing examples have been given somewhat in detail, for the purpose of showing what has already been done with fossil plants, and to indicate the lines along which, it is hoped, increased assistance will be rendered geology in the future. These

examples have designedly been confined almost exclusively to North America, and while additional ones might have been given within this area, but more particularly in other countries, enough has been presented to indicate that paleobotany may be relied upon to supply a series of stratigraphic marks in every way as reliable for the cases they cover as those supplied by any of the other branches of paleontology.

F. H Knowlton.

WAVE-LIKE PROGRESS OF AN EPEIROGENIC UPLIFT.[1]

To the ancient Greeks the word *epeiros*, specially applied to the land lying next north, signified also, in general, any mainland or continental area, as contrasted with islands or their own peninsular country. From this word Gilbert has recently supplied to our science the terms *epeirogeny* and *epeirogenic*, to designate the broad movements of uplift and subsidence which affect the whole or large parts of continents and of the oceanic basins.[2] Previously the correlative terms *orogeny* and *orogenic* had come into use, denoting the process of formation of mountain ranges by folds, faults, upthrusts and overthrusts, affecting comparatively narrow belts and lifting them in great ridges, while the epeirogenic movements of the earth's crust produce and maintain the continental plateaus and the broad depressions which are covered by the sea.

During the closing part of the Tertiary era and the present Quaternary or Psychozoic era, both epeirogenic and orogenic changes have been in progress on many portions of the earth, and on a scale of grandeur probably never before surpassed. Where these movements have raised continental regions or mountain districts to much greater altitudes than they now retain, if they were situated within the range of prevailing air currents abundantly laden with moisture and were at latitudes so far from the equator that the precipitation was chiefly snow throughout the year, they became for a time enveloped by ice-sheets, which have left the surface strewn with glacial and modified drift. Fjords, and now submarine continuations of river

[1] Presented before the World's Congress on Geology, auxiliary with the Columbian Exposition, Chicago, August 25, 1893. This paper is an attempt to answer, by a definite example, a portion of the inquiries in an editorial of the JOURNAL OF GEOLOGY, Vol. I, page 298, April–May, 1893.

[2] "Lake Bonneville," Monograph I., U. S. Geological Survey, 1890, p. 340.

valleys, attest for the northern two-thirds of North America such late Tertiary and Quaternary epeirogenic uplift at least 2,000 to 3,000 feet above the present height of this continent; for the British Isles, Scandinavia, and probably the greater part of Europe, an uplift 1,000 to 4,000 feet higher than now; and for the western side of Africa within a few degrees both north and south of the equator, 3,000 to 6,000 feet.[1] Attending the subsidence of these areas, greatly increased altitudes have been given by folding, rifts, and upthrusts, to large portions of the highest mountain systems of the world, as the Alp-Himalayan and Andes-Cordilleran belts.[2] The most recent of all mountains, excepting volcanic cones, probably is the lofty St. Elias range, according to Russell's observations; and the belt in which this is a part has an extent of two-thirds of the circumference of the globe, from Cape Horn to Alaska, the Aleutian Islands, Kamtchatka, the Kuriles, Japan, and the Philippine islands, intersecting the eastern part of the Alp-Himalayan belt near Krakatoa, in the earth's most volcanic and seismic district.

The drift-bearing areas in North America, in Europe, and in Patagonia, which at the end of their epoch of gradual elevation and fjord erosion had become deeply covered by land-ice, sank under its weight until when the ice melted away they mainly stood somewhat lower than now. The shores of the sea at that time in the St. Lawrence and Ottawa valleys, in the basin of lake Champlain, and about Hudson bay, have been again uplifted,

[1] J. W. SPENCER, Bulletin, Geol. Soc. Am., Vol. 1., 1890, pp. 65–70 (also in the Geol. Magazine, III., Vol. 7, 1890, pp. 208–212). J. D. DANA, Am. Jour. Sci., III., Vol. 40, pp. 425–437, Dec., 1890, with an excellent map of the Hudson submarine valley and fjord. G. DAVIDSON, Bulletin of the California Academy of Sciences, Vol. 2, 1887, pp. 265–268. T. F. JAMIESON, Geol. Mag., III., Vol. 8, pp. 387–392, Sept., 1891. J. Y. BUCHANAN, Scottish Geographical Magazine, Vol. 3, 1887, pp. 217–238.

[2] H. B. MEDLICOTT and W. T. BLANFORD, Manual of the Geology of India, Calcutta, 1879, Part I., pp. lvi, 372; Part II., pp. 569–571, 667–669, 672–681. J. LE CONTE, Am. Jour. Sci., III., Vol. 32, pp. 167–181, Sept. 1886; Bulletin, Geol. Soc. Am., Vol. 2, 1891, pp. 323–330; Elements of Geology, third edition, 1891, pp. 250–266, 589. J. S. DILLER, Eighth An. Rep., U. S. Geol. Survey, for 1886–87, pp. 426–432; JOURNAL OF GEOLOGY, Vol. 2, pp. 32–54, Jan.–Feb., 1894. I. C. RUSSELL, National Geographic Magazine, Vol. 3, 1891, pp. 172, 173. W. UPHAM, Appalachia, Vol. 6, 1891, pp. 191–207 (also in Pop. Sci. Monthly, Vol. 39, pp. 665–678, Sept. 1891).

but only to a comparatively small amount, from 200 to 500 or 600 feet, after the departure of the ice-sheet. In Scandinavia, according to the investigations of Baron de Geer, the postglacial uplift has varied from a minimum of 100 feet or less at the southern extremity of Sweden, to a maximum exceeding 1,000 feet in the central part of the peninsula.[1] Likewise in South America, along a distance of 1,200 miles, from the Rio Plata to Tierra del Fuego, the land has been elevated since its glaciation, the general extent of this movement in Patagonia, as observed by Darwin, being between 300 and 400 feet.[2]

The special case of an epeirogenic movement progressing like a wave, which it is the purpose of this paper to consider, is this latest, moderate uplift of North America, and especially of its central belt comprised in the Mississippi and Nelson river basins, from its depression at the close of the Glacial period. While the ice-sheet was retreating, this great area was rising as fast as its burden was removed. Close upon the wasting ice-border there followed a wave of permanent uplift of the land on which it had lain. First the loess district along the Mississippi and the upper part of this basin were elevated; next, the southern half of the area of the glacial lake Agassiz; later, its northern half; and last of all, the country enclosing Hudson bay, with which also was probably associated, as very late in its uplift, the region of the great Laurentian lakes, including lake Champlain, and of the Ottawa and the St. Lawrence. From south to north and north-east the wave of elevation advanced, and, according to Dr. Robert Bell, the rise of the land has not yet ceased about James and Hudson bays, where, in the central part of the glaciated region, we must suppose that the ice-sheet had its greatest thickness and was latest represented by lingering remnants. Having thus outlined our theme, let us return and look more

[1] Bulletin, Geol. Soc. Am., Vol. 3, 1891, pp. 65–68, with map of the late glacial marine area in southern Sweden; Proceedings of the Boston Society of Natural History, Vol. 25, 1892, pp. 456–461 (also in the Am. Geologist, Vol. 11, pp. 23–29, Jan., 1893).

[2] "Voyage of H.M.S. Beagle," chapter viii.

fully at the evidence of this progressive earth movement in the chronologic and geographic order of its successive portions.

Between the chief time of deposition of the Mississippi loess and the formation of the prominent moraines east of the Wisconsin driftless area, there intervened an uplift of the upper Mississippi region to a vertical extent estimated by Chamberlin and Salisbury as probably 800 to 1,000 feet.[1] On the western portion of the driftless area and southward to the Gulf of Mexico, the loess had been spread by very slowly flowing river floods, and partly in temporary lakes, due to the greater depression of the basin toward the north, while in the opposite direction the subsidence was insufficient to carry the low southern part of the valley beneath the sea level. The ensuing uplift probably scarcely increased the altitude of that southern area about the mouth of the Mississippi, but thence it extended northward as a differential epeirogenic movement, raising the depressed country of the central and northern portions of this great river basin several hundred feet. As a result of the changed slope, in the former place of the quiet water whose sediment was the loess, strong currents, bearing sand and gravel, flowed down the valleys from the ice-front when it amassed the moraines mentioned in Wisconsin. The duration thus represented has been supposed to comprise a long interglacial epoch, but the observations on which this belief rests seem to me to admit a different interpretation.

On the drift border, in some parts of southern Illinois and Indiana, the loess was deposited, according to Salisbury, immediately after the till which immediately underlies it, and was in part contemporaneous with the till. As soon as the ice-sheet retired from the positions where this relationship exists, the glacial drift was covered by this finer silt of the modified drift supplied by streams that flowed from the melting and retreating ice.[2] In the northeastern part of Iowa, McGee similarly finds the

[1] "Preliminary Paper on the Driftless Area of the Upper Mississippi Valley," Seventh An. Rep., U. S. Geol. Survey, for 1884–85, pp. 199–322.

[2] "The Geology of Crowley's Ridge" (1891), Geol. Survey of Arkansas, An. Rep. for 1889, Vol. 2, pp. 228, 229.

loess to have been deposited while the ice-sheet that spread the upper portion of the early till was melting away. The very remarkable paha of that district, which are eskers of loess, were accumulated while the waning ice-sheet walled them in at each side.[1] That the later part of the loess deposition was contemporaneous with the formation of the Altamont moraine, belonging to the later drift and marking its limits, I ascertained in northwestern Iowa, where this moraine along a distance of seventy-five miles, from Guthrie county northwestward to Storm Lake, is bordered on its west side by an expanse of loess as high as the crests of the morainic hills, while its elevation above the expanse of till eastward is from fifty to seventy-five feet. During the time of deposition of this part of the loess the ice-sheet reached to the Altamont moraine and was a barrier preventing the waters by which the loess was brought from flowing over the lower area of till that reaches thence east to the Des Moines river.[2] On three widely separated tracts the loess, as elsewhere the coarser portions of the modified drift forming sand and gravel plains, was in progress of deposition upon successive areas as fast as the ice-sheet supplying these stratified drift beds receded. Immediately after the land was bared by the retreat of the ice, and even while the ice itself occupied the adjoining land, the loess was being laid down, contemporaneous successively with the early till on the southern border of the drift, with the till of intermediate age in northeastern Iowa, and with the later till enclosed by the Altamont moraine. The loess deposition I believe to have been mainly continuous, accompanying the gradual and widely extended but wavering departure of the ice-sheet from its farthest boundary to this outermost of the conspicuous morainic belts.[3]

[1] U. S. Geol. Survey, Eleventh An. Rep. for 1889-90, pp. 435-471.

[2] Geol. and Nat. Hist. Survey of Minnesota, Ninth An. Rep. for 1880, pp. 307-314, 338.

[3] The interpretation of the loess and glacial history of the Mississippi basin which I here present differs widely, it must be acknowledged, from the opinions of Professors Chamberlin and Salisbury, and Messrs. McGee and Leverett, to whom we owe so much of the critical investigation of this area. These observers have been led by their

While the ice was retreating and supplying the loess, the land thus uncovered and relieved from the ice weight had been gradually rising, until it had attained approximately its present height in Wisconsin, Iowa, and southern Minnesota, before the formation of the moraines. This altitude has endured, excepting minor

studies to conclude that between the deposition of the early till in southeastern Illinois, with its accompanying loess, and that of the till and attendant paha or eskers of loess in northeastern Iowa, there intervened a very long and diversified history of glacial recessions and re-advances, including at least one prolonged interglacial epoch. A summary of these views in relation to the glacial succession in Ohio is well stated by Mr. Frank Leverett in this JOURNAL OF GEOLOGY, Vol. 1, pages 129-146, Feb.-March, 1893. From my early study, "Modified Drift in New Hampshire" (Geol. of N. H., Vol. 3., 1878, chapter i., pp. 3-176, with maps and sections), and from my later work on the Glacial Lake Agassiz, I am strongly impressed with the conviction that the deposition and ensuing erosion of the drift, both till and stratified beds, as the loess, went forward very rapidly. What these authors have ascribed to interglacial epochs, one or more of them of great length, seems to me to be more probably referable to geologically very short stages of fluctuation of the mainly waning ice-sheet.

Professor Salisbury, in the report cited, shows that there were two successive deposits of till, and a corresponding division of the loess, on and near to the boundaries of the drift; these seem to me probably due to two closely consecutive stages of ice advance, instead of the long time interval which he thinks to be indicated. Again, in the report on northeastern Iowa, to which reference was given, Mr. McGee clearly shows, chiefly by the forest bed intercalated between two sheets of till, that likewise there the ice advanced twice, with a considerable intervening time, which he supposes to have been far longer than the Postglacial epoch. To my mind, however, the forest-covered borders of the Malaspina glacier or ice-sheet in Alaska leave no doubt that forest beds enclosed in till may be due to oscillations of the ice-front within distances of no more than a few miles or even less than one mile, and that they may have required no longer interval than a few tens of years or at most a century, sufficient for the forest growth, between the times of ice retreat and re-advance.

When the depression of the ice-loaded land brought it down to so low altitude that the borders of the ice-sheet began to be melted more rapidly than they received increase by snowfall and onflow from the thicker central portion of the ice, a general recession of the glacial margin ensued. On the southern part of the drift in the Mississippi basin no continuous moraines were accumulated, and I attribute their absence principally to the attenuated condition of the ice there and its lack of a steep border. During the glacial retreat, wherever the wavering climate caused the mainly waning ice-border to remain nearly stationary during several years the vigorous outflow of the ice to its then steep frontal slope brought much drift, forming belts of irregular morainic hills and ridges, and leaving many hollows which enclose lakes. The fluctuations of the general glacial retreat seem to me to have been due principally to variations of snowfall, some long terms of years having much snow and prevailingly cool temperature, therefore allowing considerable glacial re-advance, while for the greater part other series of years favored rapid melting and retreat.

and unimportant oscillations, from that time until now. The beginning or earliest known stage of the progressive elevatory wave probably thus raised the northern half of the Mississippi basin to a variable amount ranging from 100 feet or less to 500 feet or more. It was practically completed, for this area, previous to the accumulation of the outer and earlier moraines in the series of many which mark pauses in the further recession of the ice-sheet. Thenceforward the glacial melting appears to have been more rapid than before, giving to the ice steeper frontal gradients whereby its drift was amassed more commonly in hills, ridges, and lake-enclosing hollows, and especially in the very irregularly knolly and hilly moraine belts.

The rapidity of the glacial recession and of this ensuing epeirogenic uplift in its wave-like advance upon the area of the glacial Lake Agassiz, extending nearly 700 miles from south to north in the basin of the Red river and of Lake Winnipeg, surpasses all previous knowledge in what it reveals concerning the mobility of the earth's crust. The postglacial duration of Lake Michigan and its companion great lakes of the St. Lawrence has been shown, by numerous independent but well agreeing observations and estimates, to be no longer than 6,000 to 10,000 years. Now the amount of wave erosion on the shores of Lake Michigan and the resulting accumulation of beach sand, heaped into dunes upon large areas about the south end of the lake, must exceed, by a ratio of 10 : 1 or 20 : 1, the corresponding wave action in its total amount at all the successive levels held by Lake Agassiz during its history, which accordingly must be comprised within some such time as 1,000 years or perhaps less.[1] During this geologically very short time, the ice was melted away upon the distance of 700 to 1,000 miles from the middle of the west side of Minnesota to James and Hudson bays, and the Lake Agassiz basin was differentially uplifted mostly 300 to 500 feet, to the height which it has ever since retained without appreciable later change. To understand the wave-like devel-

[1] Geol. and Nat. Hist. Survey of Canada, An. Rep., new series, Vol. 4, for 1888-89, pp. 50, 51 E.

opment of this uplift, it will be needful to consider it first for the southern half and afterward for the northern half of the glacial lake area.

About thirty successive levels of Lake Agassiz have been recognized by its beaches. A considerable number were due to the gradual erosion and lowering of the outlets, and to their changes of place and direction, first toward the south and later toward the northeast ; but probably more than half of this whole series of lake levels are distinctly exhibited only upon the central and northern portions of the lacustrine area, being due chiefly to its differential uplift increasing from south to north, and in a small degree to the decrease in the gravitative attraction of the waning ice-sheet. The five well defined beaches near the south end of this ancient lake, named in descending order the Herman, Norcross, Tintah, Campbell, and McCauleyville beaches, formed at the successive levels of southward outflow as the channel was deepened, are each found to be represented, when they are followed northward, by two, three, or more, so that near the international boundary and in Manitoba, they become subdivided into no less than seventeen beaches, marking the stages of the subsidence of the lake and in larger proportion of the differential elevation of the land. Nearly as many other lower shore lines record the stages of the lake while it outflowed northeastward. My surveys of these shores, with exact mapping and leveling, extend more than 300 miles from the south end, to lakes Winnipeg and Manitoba and the Riding Mountain.[1]

In this southern half of the whole extent of Lake Agassiz, the shore of its highest or Herman stage, as represented at the north by the uppermost of its divided beaches, has now a northward ascent of about 35 feet in the first 75 miles north from Lake Traverse, which lies in the old channel of southward outlet, about 60 feet in the second 75 miles, and about 80 feet in the

[1] Geological and Natural History Survey of Minnesota, Eighth An. Rep., for 1879, pp. 84-87 ; Eleventh An. Rep., for 1882, pp. 137-153, with map ; Final Report, Vol. 1 (1884), and Vol. 2 (1888). U. S. Geol. Survey, Bulletin No. 39 (1887), pp. 84, with map. Geol. and Nat. Hist. Survey of Canada, An. Rep., new series, Vol. 4, for 1888-89, Part E, pp. 156, with maps and sections.

third distance of 74 miles to the international boundary. Its whole ascent thus in 224 miles is 175 feet, by a slope which increases from slightly less than a half of a foot per mile in its southern third to slightly more than one foot per mile in its northern third. This beach extends only a short distance farther north, having been formed when the ice-sheet lay there as the northern boundary of the lake; but the second of the Herman beaches, slightly lower and later, reaches as far northward as to the limit of my exploration, in the vicinity of Gladstone, Manitoba, and Riding Mountain, and in this distance of 308 miles, from Lake Traverse to the latitude of Gladstone, it has an ascent of 265 feet. In the four successive nearly equal parts of its extent from south to north, namely, 75 miles, again 75 miles, then 74 miles, and lastly 84 miles, it rises respectively about 35, 50, 80, and 100 feet; and almost the whole of this change of the old beach, from its horizontality at the time of formation, has been produced by the gradual uplifting of the lake basin while the ice-sheet was retreating from it.

The considerably later upper Norcross beach rises in these distances about 25, 35, 55, and 70 feet, amounting to 185 feet in the entire 308 miles. The upper Campbell beach has ascents of about 10, 15, 30, and 35 feet, or 90 feet in all; and the lowest of the three McCauleyville beaches, marking the latest stage of southward outflow of Lake Agassiz, ascends about 5, 10, 15, and 20 feet or a total of 50 feet. It is thus seen that far the greater part of the uplift of this area had been accomplished before the formation of the Campbell and McCauleyville beaches.

Beyond the limits of my leveling, portions of nearly all the shore lines of Lake Agassiz below those of the Herman series have been observed and mapped by Mr. J. B. Tyrrell, of the Canadian Geological Survey, at localities in northwestern Manitoba and eastern Saskatchewan, bordering the northern half of this lacustrine area.[1] From a careful comparison of the eleva-

[1] Geol. and Nat. Hist. Survey of Canada, An. Rep., new series, Vol. 3, for 1887-88, Part E, pp. 16, with map; Vol. 5, for 1889-90, Part E, pp. 240, with map, sections, and illustrations from photographs.

tions of the beaches noted by Mr. Tyrrell with those determined by my surveys at the south, I am enabled to correlate very satisfactorily the two sets of shore lines. The northern continuations of the successive lake levels from the upper Norcross beach to the Niverville beaches, which mark the latest stages of the glacial lake, just before the recession of the ice-sheet from the district crossed by the Nelson river permitted it to be reduced to the Lake Winnipeg, are thus identified upon a region lying 50 to 200 miles beyond the area examined by me.

Along the base of the escarpments of Riding and Duck mountains, where Mr. Tyrrell has traced the beaches and determined their heights for a distance of fifty miles between Valley and Duck rivers, that is, between latitudes 51° 15′ and 52° N., it is found that a very important differential elevation, increasing from south to north about three feet per mile, took place after the Campbell and McCauleyville beaches were formed, since they are thus remarkably changed from their original horizontality. It is clearly shown here that the uplifting was not uniformly proportionate and regular for the whole area of Lake Agassiz. The chief movements of elevation of its southern and central part, as far to the north as Gladstone, seem not to have extended farther, at least in their full proportion. The district next to the north along an extent of 120 miles, to the north end of Duck mountain, was perhaps only so far disturbed by these movements as was necessitated to connect the rise of the country on the latitude of Gladstone with the continuing condition of maximum subsidence on the latitude of the lower part of the Saskatchewan and the north end of Lake Winnipeg. But there ensued in this district, after the date of the Campbell beach, a great differential elevation, giving to these late shore lines two or three times more northward ascent than that of the Herman beach from Lake Traverse to Gladstone; and the total change in level of the highest observed beach, probably representing the upper Norcross stage, situated at Pine river, on latitude 51° 50′ to 52° N., is approximately 400 feet, as compared with this shore line at Lake Traverse, about 420 miles distant to the south. Nearly

the whole uplift of the northern part of the basin was accomplished, however, while the ice-sheet was still a barrier of the lake, for the Niverville beach at the Grand Rapids of the Saskatchewan is only slightly higher than on the Red river, 250 miles to the south.

The southern and central part of the lake basin, reaching north to Gladstone, had been raised nearly to its present height during the first third or half of the period of the entire duration of Lake Agassiz. Then followed a time, during the second third of the lake's existence, in which the district that includes Riding and Duck mountains and extends north to the mouth of the Saskatchewan was being rapidly uplifted. But this later northward and northeastward advance of the wave of upheaval had passed beyond the Saskatchewan before Lake Agassiz was lowered to Lake Winnipeg, as is shown by the nearly level Niverville beaches. The rise of the land approximately to its present height is thus known to have followed close upon the glacial recession by which the land was relieved of the ice weight.

Latest of all, when Lake Winnipeg and the Nelson river had come into existence, the shores of Hudson and James bays were raised 300 to 500 feet from their late glacial marine submergence.[1] The remnants of the ice-sheet in that region were not melted away until much later than the glacial retreat from the northern United States and Manitoba. Moving onward with the departure of the ice, the uplifting wave of the earth's crust has raised the basin of Hudson bay 300 to 500 feet since the sea was admitted to it, and the upheaval there is not yet completed. Though doubtless slower than at first, it is still in progress, according to Dr. Bell's observations, at a probable rate of five to seven feet per century. During this last portion of the epeirogenic uplift of our continent from its Champlain depression, the whole area of Lake Agassiz, as shown by the still horizontal

[1] DR. ROBERT BELL, Geol. and Nat. Hist. Survey of Canada, Reports of Progress, for 1871-72, p. 112; for 1875-76, pp. 340; for 1877-78, pp. 7 and 32 C and 25 CC; for 1878-79, p. 21 C; for 1882-84, pp. 26-32 DD; Annual Reports, new series, Vol 1. for 1885, p. 11 DD; Vol. 2, for 1886, pp. 27, 34, and 38 G.

Niverville beaches, lay undisturbed. The loess region of the Mississippi valley, having been earliest and permanently uplifted, suffered no further change during the progressive elevation of the Lake Agassiz basin ; and that in its turn was at rest while the great area of Hudson bay has been undergoing elevation.

Having already shown that the entire duration of Lake Agassiz was about 1,000 years, we must conclude that the uplift of its area, probably to heights ranging from 100 feet to mainly about 500 feet, occurring first at the south and later at the north, took place, when in most rapid movement upward, at rates of a half a foot to one foot per year. A century, therefore, would comprise an elevation of 50 to 100 feet. The movement, however, was evidently more or less intermittent, with pauses of slower uplift or stages of rest, when the successive beach ridges were formed. Nowhere else in the records of present or past epeirogenic movements of any region have so rapid changes of level of large tracts been ascertained ; and these changes seem clearly to have occurred through a gradual deformation of the earth's crust by quiet flexure, not by faulting and earthquakes, which would break the regularity and continuity of the ascents of the beaches when traced long distances. The preglacial epeirogenic uplifts of drift-bearing areas, also apparently taking place without faulting, was probably much slower ; but their final depression beneath the ice-sheet may have been even considerably more rapid. Very sudden and great, yet not seismic, uplifts of extensive areas, as supposed by Prestwich for southern England and Wales, to account for the "head" or "rubble drift,"[1] and by Shaler for the coastal border of New England, to explain the origin and preservation of the kames,[2] seem, at least in my opinion, to be physically impossible.

The probable nature of epeirogenic movements, in their dependence on conditions of the earth's crust and interior,

[1] Quart. Jour. Geol. Soc., Vol. 48, 1892, pp. 263-343, with many sections and a map.

[2] U. S. Geol. Survey, Seventh An. Rep., for 1885-86, pp. 310, 320, 321 ; Bulletin No. 53, 1889, "The Geology of Nantucket," pp. 44, 45.

remains to be briefly noticed. Between the epochs of mountain-building by plication, the diminution of the earth's mass produces epeirogenic distortion of the crust, by the elevation of certain large areas and the depression of others; and these effects have been greatest just before relief has been given by the formation of folded mountain ranges. Two epochs have been preëminently distinguished by extensive mountain plication, one occurring at the close of the Paleozoic era, and the other progressing through the Tertiary and culminating in the Quaternary era, introducing the Ice age. During the last, besides plication and overthrust faulting of the Coast range, the St. Elias range, the Alps, and the Himalayas, a very extraordinary development of tilted mountain ranges, and outpouring of lavas on an almost unprecedented scale, have taken place in the Great Basin and the region crossed by the Snake and Columbia rivers. With the culminations of both of these great epochs of mountain-building, so widely separated by the Mesozoic and Tertiary eras, glaciation has been remarkably associated, and indeed the ice accumulation appears to have been caused by the epeirogenic and orogenic uplifts of continental plateaus and mountain ranges. These processes are well consistent with Dana's doctrine of the general permanence of the continents and oceanic basins; for upheaval of an ocean bed would not diminish but increase the earth's volume. The late glacial and postglacial uplift of North America from its Champlain depression, by the wave-like movement which has been here described, seems an effort of the earth to regain the state of isostasy, or flotation of the crust on the heavier mobile interior, which is capable of flow, whether it be solid or molten.

WARREN UPHAM.

THE OCCURRENCE OF ALGONKIAN ROCKS IN VERMONT AND THE EVIDENCE FOR THEIR SUB-DIVISION.

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CONTENTS.

GEOGRAPHY.

The area of the Pre-Cambrian rocks forming the subject of this paper[1] is quite limited in comparison with the probable extent of these rocks in Vermont. Personal reconnaissance work has detected them existing from the town Stratton on the south to Rochester on the north, a distance of fifty miles. In only a part of this area has detailed work been done, viz.; from Weston to Chittenden. On the east the district is bounded by Plymouth Valley; on the west by Rutland Valley, an area of about 240

[1] The work, of which this paper forms a partial result, was done under the immediate supervision of Mr. Raphael Pumpelly, then in charge of the Archæan Division of the United States Geological Survey, to whom my greatest thanks are due for useful counsel and advice. It is not to be understood that he is necessarily in perfect accord with me in any views advanced here.

square miles. This area has a maximum width on the south of ten miles and a minimum width on the north of four miles. The delimitation of the Pre-Cambrian as just given is only approximate, as in many localities data for its separation from overlying rocks are lacking.

TOPOGRAPHY.

The Geological Survey has lately issued topographic maps of nearly all the territory embraced in the above-outlined area; in them the pronounced relief of the country is well shown. These maps are the Rutland and Wallingford sheets. An inspection of the topography reveals a line of high elevations on the west, with steep slopes to the east, and steeper slopes commonly on the western side. This line of mountains extends from the southern limit of the Wallingford sheet to the northern limit of the Rutland sheet, and is only broken by narrow transverse valleys where lateral streams come in from the east or southeast and join Otter creek in the Rutland valley. On the east side of the area a similar range of high mountains extends the same distance, but coalesces with the western line in the northern part of the Rutland sheet. The convergence of the two lines is geologically dependent on a narrowing of the series of folds, which originally mantled over the central part of the area. North of Ludlow mountains an offset to the east occurs which carries the line slightly to the east of the Wallingford sheet.

It will be noticed on the Wallingford sheet that there is a central area between the border line of mountains of relatively much lower elevations. From Copperas hill in Shrewsbury one observes that the mountains appear to encircle him with a line of much higher elevations. In a country of strong relief one is always impressed with a sense of being in the centre of a series of elevations of greater height than those in the immediate vicinity. But from Copperas hill the impression is borne out by a glance at the topographic maps. On the east and west are the two lines of mountains just described; to the south, but farther away, the country begins to rise towards the high peaks of Stratton and Somerset; to the north, just north of the town of Shrewsbury

the high summits of Mendon, Killington and Shrewsbury extending east and west shut off the view in this direction. The lowest part of this amphitheatre is just northwest of Cuttingsville where Mill Creek has cut down to an elevation of 1000 feet above the sea. Killington Peak marks the highest point to the north, 4241 feet. The Central Vermont Railroad finds the lowest pass in the southern part of the range through this amphitheatre at Summit Station, 1500 feet above the sea.

Standing on the summit of Killington a wilderness of mountains meets one's view; the Taconic Mountains on the west and southwest; the Adirondacks to the northwest; far away northeast the White Mountains are plainly visible and the sharp outlying peaks, Monadnock, Kearsarge and Wachusett are seen to the southeast. The summits of all these mountains, with the multitude of peaks in Vermont, have the appearance of a remarkably uniform height about which numerous narrow valleys are seen; their relatively uniform height can safely be referred to an ancient base-level plain, in which upon elevation the north and south gently-flowing streams were quickly cut along the linear limestone belts, hastening and causing the development of the torrential lateral streams that flow east and west from the Green Mountain divide. It is to this torrential character of the streams and the schistose nature of the rocks that the sharp, angular topography in large part seems to be due. Rutland and Plymouth valleys, some twelve miles apart on either side of the range, are deeply cut in limestone—the former at Rutland to a depth of 500 feet above the sea. The great cutting power of the streams flowing into this valley from the east is thus seen to be due to a fall of over 3000 feet in a distance of six miles. The Green Mountain divide is about midway between these two valleys. Relatively less pronounced topographical features characterize the amphitheatre; sharp, high elevations occur, which are capped by more resistant rocks than those making up the main central area. It is between the lower rocks of this central depression and the formation along the east and west borders and to the north that an unconformity separating the rocks

below the Olenellus quartzite into two periods is thought to occur.

GEOLOGY.

Outline of the views previously held regarding the structure and age of the Green Mountains.—As far back as 1845, Adams in his first Annual Report on the Geology of Vermont[1] referred to the "Primary" system the rocks of the main range of the Green Mountains as far as the state boundary, and eastward. Among the rocks mentioned under this head which occur in the area studied by me are Green Mountain Gneiss, Mica Slate and Talcose Slate. In this report these horizons are placed below the Stockbridge limestone and the associated quartzite of the Taconic, but their relative age is confessedly unknown. In his second annual report,[2] however, he leaves the problem as to whether these are "Taconic," "Primary," or "Metamorphic," an open question, but still inclines towards a belief in their primary origin. This belief is inferred from his statement that the evidence goes to show that the limestone and quartzite of Plymouth valley on the east side of the range is equivalent to the Stockbridge limestone and quarzite on the west side, making the core of the Green Mountains the older. Adams in no place makes the statement that the belt of primary rocks represents the axis of the range, and it is doubted if he had any clear conception of the relations of the rocks on the east and west sides of the Green Mountain divide. In 1847, however, Edward Hitchcock gave two sections in his text book of Geology[3] of the Green Mountain anticline partially and completely folded as we see it to-day. The anticline is represented as overturned slightly to the west, with a flat crest and a rude fan-shaped cross-section; the text[4] mentions that the strata grow newer as one goes westerly, although apparently the series is descending. Such a conclusion reached at that time is the happy result of a coincidence of schistosity and stratification at

[1] p. 62.

[2] Second Annual Report on the Geology of Vermont. Adams, 1846, p. 168.

[3] Elementary Geology, Edward Hitchcock, 1847, figs. 27 and 28, p. 37.

[4] Opus. cit., p. 36.

the localities examined by him ; in a general way the structure is that of an overturned series of folds, of an extremely complicated nature. These sections were made particularly to illustrate the structure of Hoosac Mountain, and the structure suggested in 1847 finds its verification in 1889[1] in Massachusetts, as far as the overturning of the anticline to the west is concerned. At that time little reference was made to the age of the rocks exposed along the axis, but they were mentioned as probably older than the Lower Silurian, while their relation to the younger rocks was not considered.

Zodack Thompson, in 1856, in considering the "Taconic System," makes reference to the structure of the rocks along the Green Mountain range[2].

He remarks that "one of the most marked peculiarities in the geology of Vermont is found in the general dip of the stratified rocks, which is, with a few trifling exceptions, toward a synclinal axis extending north and south near the center of the Green Mountain range." He notes a general westerly dip on the east side of the range, and an easterly dip on the west side. However, the question as to whether the Green Mountain rocks are really primary or post-Taconic was with him still in doubt, but he states that the weight of the evidence points towards the latter view, or more recent age.

In 1868, T. Sterry Hunt, after a study of the literature, while discussing Vermont geology, comes to much the same conclusion as Thompson.[3] To use his own words : "All the evidence, palæontological and stratigraphical, as yet brought forward, affords no proof of the existence in Vermont of any strata (a small spur of the Laurentian excepted) lower than the Potsdam

[1] See part 3, "Geology of the Green Mountains in Massachusetts," by R. Pumpelly, J. E. Wolff, T. Nelson Dale, and Bayard T. Putnam. Monograph U. S. Geol. Survey. Submitted in 1889. Not yet issued.

[2] Preliminary Report on the Natural History of the State of Vermont. Augustus Young. 1856. Extract from Zodack Thompson's address on the Natural History of Vermont. App. 6, p. 67.

[3] On some points in the geology of Vermont, T. Sterry Hunt, Am. Jour. Sci., 2d series, Vol. XLVI., 1868, p. 229.

formation * * * ." The gneiss of the Green Mountains is by him and by the geological survey of Canada referred to the Quebec group and a synclinal structure is assigned to the range probably largely on the basis of the views of Thompson. It is thus seen that Adams' suggestion of the anticlinal nature of the mountains and their "primary" age are passed over, as well as the more recent work of the elder Hitchcock, to which reference is made below.

Anything like a close study of the Green Mountains was not attempted until 1861, when the two Hitchcocks finished their work on the geology of the state.[1] Under the head of Azoic Rocks,[2] Charles H. Hitchcock places the Vermont rocks occurring east of the Stockbridge limestone as far as the Connecticut river, and includes therein the basal quartzite of Emmons' Taconic system, although the elder Hitchcock admits finding therein traces of life in the shape of Scolithus and a species of Lingula[3] which were not deemed sufficient evidence to warrant classifying this horizon with the fossiliferous rocks. The younger Hitchcock divided the azoic rocks as follows: Gneiss (Adams' Green Mountain Gneiss) hornblende schist, mica-schist, clay-slate, quartz-rock, talcose schist, serpentine and steatite and saccharoidal limestone. The most western member, the quartz-rock or quartzite with its associated conglomerate is mapped as extending the whole length of the state. Just north of the area studied by me it is represented as thinning out and giving place to "talcose conglomerate."[4] On the east side of the mountains a narrow strip is colored in extending through the towns of Plymouth and Ludlow. Lithological similarity is used as a basis for the correlation of the conglomerate, which underlies the "quartz-rock" at Wallingford with the Shawangunk Grit or Oneida Conglomerate of New York. The quartzite or quartz-rock is referred for

[1] Geology of Vermont, 1861, 2 volumes.

[2] Opus. cit. Vol. I., pp. 452 to 453.

[3] Opus. cit. Vol. I., p. 500.

[4] Opus. cit. See geological map of Vermont. Pl. I., Vol. I.

palæontological reasons to the Medina, and the hypothesis is advanced that by the removal of silicates by circulating waters metamorphosis of the quartz-rock to the conglomerate has taken place. Reference will be made again to this conglomerate in the following pages. Under the head of Gneiss, rocks of great variation are grouped. Eight principal varieties dependent on accessory minerals such as hornblende and epidote are enumerated. The gneiss is represented as a slightly curving band, extending from the Massachusetts line nearly to the north end of the state, gradually narrowing to a point. In the south-eastern part of the state another shorter lense is mapped, but this has not been explored by the writer. The relations of the gneiss to the conglomerate or quartz-rock are not dwelt upon, but many phases are assigned to metamorphosed Lower Silurian rocks, while the probability that even older rocks may be exposed along the anticlinal axis in the range proper, or to the east is regarded as a possibility. A deficiency of feldspar is remarked upon; because of this peculiarity, according to Hitchcock, Adams called it "Green Mountain Gneiss to distinguish it from true gneiss." [1] Seven years later (1868) C. H. Hitchcock abandoned his theory as to the age of the quartzite,[2] and in a new classification refers it to the Potsdam group. The Talcose conglomerate is placed in the "Lauzon" group of the Lower Silurian, while to the Eozoic system the Green Mountain gneiss is assigned. In placing the gneiss in the Eozoic he does not infer that it necessarily is older than the Cambrian or Huronian. Several reasons are enumerated for referring it to this system, the strongest one being the evidence afforded by the occurrence of pebbles in the Talcose comglomerate at the base of the Potsdam derived from gneissic rocks. An unconformity beneath the Potsdam points to the Eozoic age of the lower rocks.[3]

The suggestion made by Adams (above mentioned) that the Green Mountains are an anticlinal fold, is followed, in

[1] Opus. cit. Vol. I., p. 454.

[2] The Geology of Vermont, Proc. Amer. Asso., 16th meeting, 1868, p. 120.

[3] Opus. cit. p. 122.

1861, by the statement of the elder Hitchcock that such is the structure. Numerous sections across the range are given in which its anticlinal nature is brought out. Much evidence is adduced in the text pointing to the same conclusion based mainly on the occurence of a quartzite and conglomerate on both sides of the range associated with limestones. Edward Hitchcock, in 1847, had published sections which represented the range as an anticline slightly inverted by overturning towards the west. Adams, in 1845, had somewhat disconnectedly stated that the "granular quartz-rock" of the Taconic had an inverted dip,[1] but did not include in the Taconic rocks east of the quartz rock.

In all, the geology of Vermont (1861), contains twelve sections east and west across the State. Of these, eleven traverse the Green Mountain gneiss; the four southern ones show several synclines and anticlines in the gneiss; section V, one broad anticline; sections VI, VII, and VIII represent the anticline overturned to the west; and in sections IX, X, X^a, and XI the gneiss is given a simple anticlinal structure. On the west side of the range, in all sections except the fifth, the quartz rock is given an easterly dip of varying angle due to inversion. With one exception, at North Bennington, where the quartzite dips easterly at an angle of 5° to 20°, nearly in the position it was laid down, the writer has not seen an easterly dip in the rock along this belt as far north as Pittsford. The rock is usually quite massive and flinty, and bedding is not discernible. An easterly-dipping jointing is easily mistaken for stratification. Rocks immediately below have a lamination that dips easterly at a high angle, and the inversion argued is based largely upon observation on this structure; the coincidence of lamination and bedding along the western border has already been spoken of as the probable reason of the elder Hitchcock's accurate decipherment, in 1847, of the real altitude of the main axis of the mountains in Massachusetts. In 1868 the younger Hitchcock reiterated the interpretation

[1] First Annual Report on the Geology of Vermont, 1845, p. 61.

of his father, as to its anticlinal structure, and cites as proof the supposed equivalence of the "Potsdam" and "Levis" rocks on both sides of the range in Wallingford and Plymouth.[1]

THE PROBLEM OUTLINED.

From the opinions held as to the age, character, and structure of the Green Mountain axis just given, the main facts that stand out most prominently are that the centre of the mountains is occupied by strata to which the name gneiss is universally given, and that bordering this, on the west, occurs a terrane variously called "granular quartz," "quartz rock," and "quartzite," by different authors, together with an associated conglomerate. These last two rocks have been referred to various horizons from the Azoic to the Medina sandstone. Most geologists have grouped the central gneiss among the oldest, although Thompson considered it more recent than the Stockbridge limestone.

The relations of the conglomerate to the quartzite are by no means so simple as the older geologists were disposed to believe. Between the conglomerate and the quartzite there is an extensive series of metamorphosed sedimentary rocks which have been overlooked in the past, and which are in part the subject of this paper. Beneath the conglomerate horizon the gneisses and other rocks occurring in the amphitheatres, with their interstratified limestones and quartzites make a second series composed wholly or partly of sedimentary rocks separated from the first, of which the conglomerate is the base, by an unconformity sufficiently well identified to warrant a sub-division of the Pre-Cambrian Algonkian terranes into two series.

REASONS FOR REFERRING THESE ROCKS TO THE ALGONKIAN.

It is due to the labor of Mr. Walcott that the age of the quartzite on the western border of the range has finally been determined definitely. Upon palæontological evidence he refers it to the Lower Cambrian horizon and makes it equivalent to the red sand rock of Georgia, Vermont; the latter being an offshore, and the former a near-shore deposit. In his Cambrian

[1] The Geology of Vermont, Proc. Amer. Assoc. 16th meeting, 1886, p. 121.

correlation paper[1] Mr. Walcott represents, probably hypothetically, the quartzite lying unconformably upon Pre-Cambrian (Algonkian) strata. The evidence for a time-break at Clarksburg Mountain in Massachusetts is undoubted, but farther north the relation of the quartzite to the subjacent rocks is much more obscure. As to the age of the subjacent terranes in Rutland County, Mr. Walcott refers them to the Archæan.[2] Since the Olenellus fauna, as determined in Vermont, delimits the base of the Cambrian horizon, all the sedimentary rocks below (adopting the classification of the U. S. Geological Survey) must be referred to the Algonkian. As mentioned above, the quartzite along the border is considered a near-shore deposit, and as such, it is evidence in itself of an approximate subjacent delimitation of the Cambrian sediments. On lithological grounds alone it would be correlated at once with the Potsdam on the eastern border of the Adirondacks, not thirty-five miles west of Wallingford, where the base of the Upper Cambrian is plainly seen resting unconformably upon the lower gneisses. The Potsdam is only faintly conglomeratic at the bottom, and the same is true of the quartzite in Vermont; so that in Vermont, at least, we are apparently without a true basal conglomerate in the Cambrian. The Lower Cambrian lies directly upon granitoid gneiss twenty-five miles south of Wallingford, where the contact is depositional with no conglomerate whatever. These occurrences indicate that we are not obliged to postulate still lower members of the Olenellus horizon on the ground that the base as there shown is not delimited by a conglomerate. In all the localities in Vermont examined by me a reversed dip in the quartzite on the west side of the range has not been observed; in the stratified series just below overturns occur along this line. This may be cited as evidence of discordance at the base of the Olenellus quartzite, as it is extremely unlikely that pronounced overturning could have taken place without involving the quartzite in its folds. That a thick

[1] Correlation Papers, Cambrian; Bulletin U. S. Geological Survey, 1890, Pl. II, theoretical cross-section at bottom of page.

[2] See Geologic column No. 8, opus. cit. p. 366.

bed of massive quartzite might not be affected by minor folds is recognized, as it is well known to be among the most resistent rocks. The series below, however, possesses quartzites still more massive and flinty, rocks which have been involved in close flexures as sharp as those in fissile associated beds. Through Massachusetts and southern Vermont the quartzite is remarkable for its persistence. The series immediately beneath is extremely variable in character and thickness due to original deposition and to the metamorphism that it has suffered. This series may be wanting, as on Clarksburg Mountain and at North Bennington, Vermont, where the quartzite lies unconformably upon crystalline gneisses.

In Walcott's hypothetical section across this continent, the Cambrian ocean is represented as sending a long arm up the Rutland Valley not covering the Green Mountains or the Adirondacks. Careful search through the Green Mountains proper has not resulted in finding any traces of the quartzite, there is no evidence that it once mantled over the range, although it is not unlikely that the Plymouth Valley was once occupied by Cambrian waters. There are abundant occurrences, however, of the lower series in the heart of the range, where many of the highest peaks are capped by one member or another. There is stratigraphical and microscopical evidence that this series has undergone repeated disturbances; the quartzite exhibits but one. This fact cannot be used legitimately as evidence of disparity in age, as it is probable that the thick bed of quartzite stood like a bulwark among more variable, less-resistant strata, not taking part in and not recording orographic movements unless of extreme intensity. It should not fail to be stated that in many localities the quartzite lies directly upon fissile mica schist, the upper member of the series below in apparent conformity therewith, and the difficulty of referring the schist to the Lower Cambrian or the Algonkian is apparent. I am disposed to believe it of the latter age and to make it the uppermost member of an upper series with the metamorphic conglomerate delimiting the series below. There are many reasons for this view, some of

which have been given. The limits of this paper will not permit anything like a full analysis of the evidence, which must be reserved for some future time. It seems generally, however, to be accepted that sedimentary rocks below the Olenellus horizon shall be considered to belong to the Algonkian. But few forms of the characteristic fauna of the Lower Cambrian are known to extend below this horizon; no fossils have been discovered in the big Cottonwood section in Utah, where 12,000 feet of silicious states and sandstone lie conformably below the olenellus zone. It is safe to assume that through such a vertical extent of rock the typical Olenellus fauna will not range, and consequently part at least must be placed with the Algonkian. That a part of the Vermont rocks immediately below the quartzite may be proven in the future to belong with the quartzite above is recognized, but the trend of the evidence collected by me points toward its classification in part at least with the Pre-Cambrian sedimentary rocks. Without commenting, the reasons for and against this view may be concisely stated, as follows: 1. Extreme diversity of the metamorphic series, or great lithological difference, as compared with the quartzite horizon. 2. Evidence of profound orographic movements in the latter not observed in the former, the folds often occuring overturned to the west. 3. Occurrence of the quartzite reposing discordantly upon granitoid gneiss not far south of the area under discussion and also near by in New York. 4. The near-shore character of the quartzite. 5. The fact that the quartzite does not occur in the heart of or to the east of the range, whereas the series below has been traced across the mountains. 6. In general, the converging of the gneiss-area shown on Hitchcock's map of the State[1] indicating a northerly-pitching anticline, and in detail shown in small flutings, while the quartzite does not exhibit this feature. 8. The occurrence of undoubted Algonkian rocks near by, south of Hoosac Mountain in Massachusetts identified by Mr. Emerson,[2] who finds Lower

[1] Geology of Vermont, 1861.

[2] See Geological Atlas of the United States, Hawley Sheet, 1892, B. K. Emerson. Members of the Algonkian Period are briefly described on Sheet No. 4.

Cambrian conglomerate gneiss resting unconformably upon the upturned edges of a coarse gneiss associated with coarsely-crystalline limestone (Emerson's Hinsdale limestone). A line of Algonkian rocks extends southward from Hoosac Mountain (including the Stamford gneiss forming the core of the mountain) in a belt of oval areas across the Berkshire County Plateau. On lithological grounds these rocks would be correlated with some members of the Mount Holly series of Vermont to be described below. They may, however, be equivalent to the upper series of the Algonkian which has suffered less metamorphism to the north. The lack of fossil remains in the lower series cannot be used as evidence, since metamorphism has probably obliterated all traces of them. A disparity between induced structures in the two belts is also of no value as the quartzite has not recorded the regional cleavage owing to its massive character. Rocks stratigraphically above it, however, may have had the cleavage developed. The evidence against this delimitation is furnished by the apparently conformable mica schist, which, as a rule, accompanies the quartzite, and more locally other members of the series as well, which may have contained the Olenellus fauna. It must be left for future work to determine beyond dispute the relations of the series immediately below the Olenellus zone to the quartzite, whether the rocks are conformable or unconformable ; if the former, whether the delimitation of the Lower Cambrian shall be placed above the mica schist or below it. Tentatively, the series just below the quartzite, the mica schist at the top and the conglomerate at the bottom, will be considered wholly or in part of Algonkian age. The separate members of this series with estimated thicknesses will now be described.

THE UPPER OR MENDON SERIES OF THE ALGONKIAN.

As far as known the best section of these rocks occurs in the town of Mendon, one mile north of Mendon village, on the west slope of Blue Ridge Mountain (Rutland Sheet). All the members identified occur here, although no single section thus

far examined has all the members developed characteristically or of maximum thickness. Each member thins out and thickens along its strike in the most remarkable manner. On Nickwacket Mountain, just north of the Rutland Sheet, for example, the pebbly, micaceous quartzite member attains its greatest thickness, and the pebbly limestone as well; while in the heart of the range, east of the Chittenden flats the lower quartzite-conglomerate horizon attains its maximum development. The mica schist is best seen along the Mendon section. Provisionally, therefore, for descriptive purposes the name Mendon Series will be given these rocks.

That the relations of the different members of this series could be worked out seemed for a time a hopeless task, as it was subject to such great variations in character, and was so intimately folded, but the order given below, from less disturbed localities is correct within narrow limits. The thickness of the different beds is estimated, such estimates being based upon great familiarity with them in widely-separated localities, and under various habits due to metamorphism. The estimates are well within the limits of maximum variation.

Beginning with the Olenellus quartzite which strikes N. 5 W. to N. 5° E., the next rock, as mentioned above, descending geologically, is a mica schist. It occurs along the west base of the hill, situated in the northwest corner of Mendon. Near the quartzite it appears conformable, but as one ascends the hill, going east, the rock becomes more crumpled; two hundred feet from the quartzite the stratification has been practically destroyed, while the regional schistosity, characteristic of the Appalachian range in New England, takes its place. This induced structure, along the borders of the range strikes quite uniformily N. 10° to 15° E., dipping commonly between 60° and 80° easterly, although westerly dips are noticed. The structure of the schist consists of minute plications and larger ones many feet across, closely folded and often overturned to west. Minute faulting along the axis of the crenulations has produced the schistosity (ausweisungschiefer) which has been

mistaken for the dip by the early workers in this region. A line drawn tangentially across the apices of the serratures shows the dip to be some 45° westerly in the upper (westerly) part. In this section the schist may be safely assumed to have a thickness of 800 feet. In some localities it is not over 50 feet thick, but just south of Chittenden village more than 1000 feet occur. All through the area the schist carries abundant lenses of secondary quartz introduced along the bedding and cleavage planes. These are considered genetically to be the excess of silica, resulting in great part from the decomposition of silicates originally in the rock, the alumina and potassium going to form the muscovite. Phases of the rock are without such lenses and are nearly free from quartz ; other phases are largely quartz layers with thin folds of mica between. Some phases carry secondary feldspars, but they are exceptional. Under the microscope the normal constituents of the schist are seen to be a varying percentage of chlorite, a great deal of muscovite in slender, closely-packed plates and quartz in thin layers and scattered through the rock. Biotite in larger flakes is also universally present, with occasional feldspar grains.

Beneath the schist is the micaceous quartzite horizon, poorly represented in this section, but on Nickwacket Mountain having a thickness of 500 feet at least, and carrying several thin beds of crystalline limestone. Here there are not over 100 feet, with no interstratified limestone beds. It has scattered through it abundant pebbles of feldspar (microcline and orthoclase) besides quartz. The pebbles are small and have undoubted clastic outlines. Owing to their occurrence, this horizon is particularly easy to identify. Its strike is a little west of north, and the dip 80° easterly. Going east from the Olenellus quartzite the dips have grown continually steeper and now we find the rocks overturned to the west. This horizon presents many phases ; traced south five miles it becomes a muscovitic schist, highly contorted, in which there is no evidence of detrital material ; traced eastward towards the heart of the range, when caught in synclinal folds it is a granular, micaceous gneiss. Secondary feldspars

have been developed, but the larger clastic feldspar may be still detected in a fine-grained ground mass. On White Rock Mountain its place is occupied by a well-marked sandstone carrying some biotite. Microscopically the rock is made up essentially of small grains of clastic quartz. The larger pebbles of quartz and feldspar varying much in abundance in different localities. In the heart of the range a gneissose phase is produced by granulation and by development of pale-green, pleochroic muscovite and glassy plagioclase from the feldspar pebbles. The mica in the most massive phase is also green muscovite.

Immediately below the quartzite are fifty feet of pebbly, crystalline limestone, the pebbles being largely feldspar, like those in the quartzite. A narrow valley occurs here in this section due to the relatively rapid removal of the limestone. Nickwacket Mountain along its northern peak exhibits the best development of this rock, where its thickness may be safely estimated at 400 feet. It is only locally pebbly there in contact with quartzose layers or the main body of the quartzite above. Lack of persistence characterizes this work as one would expect. This seems to be due to want of, or to differences in, original deposition in many localities; to its alteration to other minerals; to its removal by solution, and to its being squeezed out during folding. The rock is locally graphitic and usually quartzose, especially where it occurs in thin beds in the micaceous pebble-bearing quartzite. Phlogopite is common in little flakes in some dolomitic varieties. All through the mountains of the Rutland Sheet it forms an easily-recognized horizon. Near the summit of Pico peak, just north of Killington, it occurs, and by its rapid removal it has given rise to escarpments on the southwest slope of the mountain.

Some fifty feet of green muscovite schist occurs next below, which may be considered a laminated phase of the micaceous quartzite which usually appears below the limestone. This grades downward into a flinty quartzite along this section. Locally the quartzite carries pebbles of quartz and as one goes east it is seen to grade into the metamorphic conglomerate that

has become so classic through the contributions of the elder Hitchcock. This horizon is one of extreme variability and no one name can be given it that will have anything like a general descriptive application. Further south Mr. Wolff has described it as a conglomerate-schist,[1] but there the percentage of feldspar, both secondary and original is large and the rock has a marked schistosity. Another phase from the Mendon section is a well-developed conglomerate in which the pebbles vary in size from a pea up to small boulders. The larger ones are nearly all of vitreous quartz, many of a fine blue color. At East Clarendon nearly all detrital material is obliterated by the shearing action that has developed the perfect lamination observed there. Exposed south of Mendon village this horizon is a vitreous massive quartzite, probably 500 feet thick, devoid of all evidence of stratification. Three miles south of there, the quartzite has disappeared and a well-laminated muscovitic gneiss, similar to that occuring at East Clarendon and Bald Mountain east of Rutland, takes its place. One mile north of Chittenden a remarkable phase occurs; the rock as a whole is still a vitreous quartzite, but it is made up almost entirely of angular and rounded boulder-like areas of the same material. The boulders seem to represent in part an original conglomerate. If boulders of a composite nature were deposited with those of quartz, the silicates have been converted into what little ground-mass the rock now possesses. After the rock was cemented into a vitreous quartzite, brecciation took place, and today we see a mixture of genuine boulders, some having a diameter of several feet, and pseudo-boulders of larger dimensions, some angular and others having rounded outlines. imitating genuine clastics. The former are identified by their occasional occurrence in a matrix or cement that has protected them from distortion or granulation. East of Chittenden flats an even greater development of quartzite occurs where its thick-

[1] Metamorphism of Clastic Feldspar in Conglomerate Schist, Bull. Museum Comp. Zoöl. Whole series Vol. XVI., No. 10, Plate II, shows two excellent microphotographs of this phase of the conglomerate where the clastic material is nearly obliterated.

ness is not less than 700 feet. Where an excess of shearing motion has operated, a well-laminated schist has resulted, examples of which may be seen at the base of the conglomerate in the Mendon section and extending north and south from there; on the summits of Pico, Killington, Mendon, Little Killington, and Blue Ridge Mountains, and in countless other localities.

Many phases of this schist occur characterized by accessories such as chlorite, biotite, and magnetite. An important and wide-spread variety carries ottrelite in prisms and radiating bundles.[1] Muscovite predominates over other micaceous minerals, both colorless and green varieties occurring, while feldspar is only sparingly present. All the varieties of this horizon occur in great confusion, grading into one another vertically and along the strike. In my notes the most schistose variety has been called Killington schist, and this with the green gneissose phase are the two most common occurrences of the rock. It seems preferable to adopt the name conglomerate-gneiss for this horizon as it is descriptive of its present mineral constitution and suggestive of its past history. All the evidences of profound dynamic movement observed in this series are observable in the quartzite along the Mendon section. In fact, no rock in the Mendon series bears evidence of so great disturbances.

Considering 350 feet to represent the thickness of the quartzite and conglomerate at this point, the total thickness of the section is approximately 1,300 feet. It is probable that in some localities there may be 2,000 feet of strata, and in the northern part of the State no doubt the formation is much more greatly developed. As a whole it is subject to great variations in thickness, and may decrease to two or three hundred feet, as on the south end of Bear Mountains in Wallingford. The relations of the conglomerate-gneiss horizon to the underlying rocks will be

[1] This phase was described by the writer in the American Journal of Science, Vol. XLIV., Oct., 1892.—An Ottrelite-Bearing Phase of a Metamorphic Conglomerate in the Green Mountains.

considered after a general description of the rocks comprising the second or lower division of the Algonkian terranes has been given.

THE LOWER OR MOUNT HOLLY SERIES OF THE ALGONKIAN.

In the amphitheatre already described, the rocks of this series occur well-developed in the towns of Mount Holly and Shrewsbury and extend south probably to near the Massachusetts line. They are perhaps no more characteristically developed in Mount Holly than elsewhere to the south, or possibly to the north, but they are best known to me there of anywhere in the State. It seems best, therefore, to designate the rocks of this central area, or core of the Green Mountains, the Mount Holly series.

In nearly every way the core rocks are contrasted with the Mendon series; these differences will be emphasized below when the question of the relations of the two series will be discussed. A description of the different consecutive members of the series cannot be given, as the rocks are too variable in character, and dynamic action has involved them in such complications. No approach has been made in the determination of the order of their occurences, and it is doubtful if such a sequence will be made for years to come, unless more discriminating criteria are forthcoming. Many unlike members there are, but they are characterized by no presistence of horizon, or if they are, metamorphism has obliterated all distinguishing features. The area appears as a multitude of patches of different kinds of rocks, whose relations with one another seem impossible of solution. Unlike the Mendon series, there is no pronounced northerly lamination agreeing in the main with the genuine strike of the stratification. The structure here is in part due to zones of unlike mineralogical composition; most of the igneous rocks have been well laminated and the gneisses and schists have their characteristic arrangement of constituent minerals.

A detailed description of all the varieties of rock occurring will not be attempted here; some of the more noteworthy areas will be

briefly mentioned. Along the south slope of a hill just south of Mechanicsville, a section is exposed showing fine-grained biotite gneiss at the base, passing imperceptibly into a sugared quartzite above. This in turn is overlain by coarse saccharoidal limestone; and a muscovitic, garnetiferous schist overlies this, capping the summit of the hill. These rocks strike in general east and west and dip northerly. A section on the southwest slope of Ludlow Mountain, two miles southeast of here, exhibits at least two beds of coarse limestone grading into tremolite and green hornblende, interstratified with layers of schist. These rocks strike west of north and dip easterly. On the southwest slope of Saltash Mountain a bed of tremolitic limestone interstratified in biotitic gneiss trends northwest. At Northam village, a similar coarse limestone occurs associated with a vitreous quartzite, a laminated eruptive rock and a rusty muscovitic schist. All through the core there are patches of these coarse limestones in a great variety of association, such as with coarse augen-gneisses (a common occurrence), quartzites, schists, and other rocks. Fine-grained, blue marbles are present in two or three localities. In all cases the limestones are in irregular lenses, and are extremely local; their occurrence with coarse gneiss affords no evidence of structure; these scattered, irregular outcroppings and differences of association make them impossible of correlation. There may be two horizons of limestone in the core or there may be a dozen. The same is true of the quartzites and other sedimentary rocks. Limestone belts are, however, frequently identified by their metamorphosed equivalent, tremolite, or in rare instances, serpentine replaces the limestone. The Mount Holly series has scattered all through it these undoubted areas of sedimentary rocks recognizable where from manifold causes they have escaped destruction or metamorphism, and their clastic characters have not been obliterated. They probably represent remnants of a once great sedimentary series older than the Mendon series.

The rocks associated with the evident clastics present a great variety of texture and mineral composition. Thin sections show, however, that the differences are mainly due to variations

in grouping of the component minerals rather than to differences of composition. Gneisses are most common, occurring as fine-grained, chloritic rocks or coarse biotite, augen-gneisses. A brownish coarse gneiss with porphyritic crystals of orthoclase extends in intermittent outcrops from Wilcox Hill on the north to Button Hill on the south, a distance of eight miles. This rock carries both biotite and muscovite, the latter evidently derived from the feldspar. In Eastham, Northam, and east of Bear Mountain, there are areas of coarse biotite gneiss with interstratified beds of quartzite and limestone. Fine-grained, chloritic schists and gneisses are abundant, as on the summit of Saltash Mountain.

The area immediately about Mount Holly village on the Central Vermont Railroad, is characterized by a great number of amphibolites. These occur as schists, either intrusive or extrusive, and as dikes, cutting one another, and the country rock. They occur interlaminated with various rocks—quartzites, gneisses and schists, and possess the local schistosity of the enclosing rock. This is as true of the dikes as of the sills, affording a conception of how far removed from any key to the real stratification is the lamination of these rocks and how faulty geological interpretation must be when deciphered on the basis of induced structures. Aside from the interest one naturally feels in eruptives as old as these, their importance as evidence in separating the Mendon from the Mount Holly series cannot be overestimated. Modern basic dikes of camptonite and other igneous rocks traverse the core rocks, but they are younger than the last disturbance of the Green Mountains, cutting Algonkian and Cambrian rocks alike.

Following the accepted definition of the Algonkian rocks, this lower series as well as the upper must be grouped as Algonkian. Although possessing many rocks undoubtedly igneous, and others whose origin is problematical, there is a considerable development of genuine sedimentary rocks, warranting us to place the whole series among the Algonkian. The evidence for this sub-division, which is based upon manifold differences between

the Mendon and Mount Holly series and their associated phenomena, will now be considered.

EVIDENCE OF DISCORDANCE BETWEEN THE MOUNT HOLLY AND MENDON SERIES.

Lithological differences.—These are many, and furnish important data for the classification of the two series into two divisions. A hasty description has already been given of the upper series and a still more imperfect one of the series below, which, owing to its vast variety of rock phase, hardly warrants a detailed description of each rock. In a large way it may be said that the upper series is prevailingly schistose; the lower prevailingly gneissic. The rocks of the upper series can all be referred indisputably to a sedimentary origin; part, at least, of the lower are of igneous origin, and a still larger part afford no criteria which will enable us to assert their origin. Coarsely crystalline limestones occurring in the core have in no case been detected in the upper rock, and pebbly limestones or quartzites are never met with in the Mount Holly series. Along the western border of the range, from Sunderland to Chittenden, none of the core rocks are seen interstratified with the Mendon series. An association sometimes occurs, but only when there is evidence for a faulted relationship. In the amphitheatre, where the lowest rocks occur, none of the upper series have been found. Farther north the lower terrane makes up but a small part of the surface rocks; the Mendon series capping all the prominent mountains as far north as Nickwacket Peak. The chaotic occurrence and lack of discoverable sequence in the core rocks find no parallel in the relatively persistent and orderly arrangement of the upper series. To the eye the core rocks have an older look; they are commonly loose-textured when weathered, crumbling often in the hand. Under the microscope, the cause for this is readily seen in the universal granulation that the rocks have suffered, a phenomenon strongly in contrast to the more coherent, less-sugared rocks of the border. Other differences in the two series are found in their mineralogical composition as a whole. Such differences

may well be due to unlike environment making deductions in favor of unconformity to a certain extent misleading, but the contrasts noticed are too strongly marked to admit of dispute as to cause.

The gneisses and schists of the older rocks are characterized by a wide-spread development. Colorless muscovite, chlorite, orthoclase, biotite, and quartz occur as essential constituents; epidote, zoisite, titanite, and garnets occur as accessories. Of these, the first four minerals occur much more sparingly in the upper series; the last three are not remembered to occur at all. Phases of the lower limestones carry tremolite or serpentine, while dark hornblende occurs in abundance. Orthoclase is relatively much less abundant in the border rocks where it occurs frequently as pebbles. Pale-green, pleochroic muscovite, secondary plagioclase, magnetite, and ottrelite, so common in the upper series, are much less abundant in the lower series; green-muscovite and ottrelite are not known to me in the central area. The limestones of the two belts may also differ as to the percentage of carbonate of magnesium present. No investigation of this subject has been attempted.

Reference has already been made to the metamorphosed basic igneous rocks, amphibolites, of the central area. One of the best sections of these rocks is displayed in the railroad-cut at Summit station, where they are exposed for nearly half a mile. Numerous separate members can still be distinguished in the mass by textural variations. They are cut by dikes of the same material and also by more modern dikes of camptonite. Such a series of amphibolites probably represents a period of volcanic activity, antedating the Cambrian, of great areal extent. Nearly everywhere, where these lower rocks are exposed, amphibolites are present also. To the north they occur only in scattered patches associated with granitoid gneiss; to the south reconnaissance work has not detected them, but they probably occur there. Mr. Wolff has described an amphibolite from a hill situated about one mile south of Mount Holly station, and he refers

it with probability to an original diabase.[1] Remains of an original bisilicate (augite) can still be found in the rocks. Whether diabase or basalt their occurrence in sheets traversed by dikes of the same material and their great abundance lead me to consider them surface flows or intrusives. Their abundance may be cited as evidence of extrusive origin since it is extremely unlikely that any area, reasoning from analogy, would be traversed by so large a number of intrusives. This view is also sustained by the fact that diabases and basalts are prevailing surface flows. Such regions as the Triassic (Newark) of the eastern United States, Keweenaw Point, the western plateau, and the Deccan being examples. Their restriction to the Mount Holly series not only points to their extrusive origin, but whatever their origin they afford almost positive evidence of an unconformity at the top of the series; if intrusive, we should naturally expect to find them occurring in the Mendon series, which is not the case; if extrusive, their occurrence only in the core rocks is even more in favor of the proposed subdivision. As to the importance of the evidence afforded by these rocks no better confirmation can be found than the following from Van Hise.[1] "Eruptive rocks are often an important guide in determining structural discordances. These are valuable when the older series has passed through an epoch of eruptive activity before the newer series was deposited. In such cases, bosses, contemporaneous or intrusive beds, volcanic fragmental material or dikes may occur in the older series which nowhere are associated with the newer. It is possible, of course, that eruptives may penetrate the inferior members of a series and never reach the higher formations; but if it is found that the supposed inferior series is associated with abundant material of igneous origin which never passes beyond a certain line, it is almost demonstrative evidence of the later age of the newer series."

[1] Geology of the Green Mountains in Massachusetts, by R. Pumpelly, J. E. Wolff, T. Nelson Dale, and Bayard T. Putnam, Monograph U. S. Geol. Survey, Part 3, submitted in 1889.

[1] Correlation Papers—Archæan and Algonkian, Bull. No. 86, U. S. Geol. Survey, p. 520.

Structural differences.— Evidence afforded by a study of the structure in the two series, both original and induced, has an important bearing upon the separation of the two terranes. Of first importance may be mentioned the relatively orderly strike of the lamination and bedding of the upper series in comparison with the strike and disordered succes-

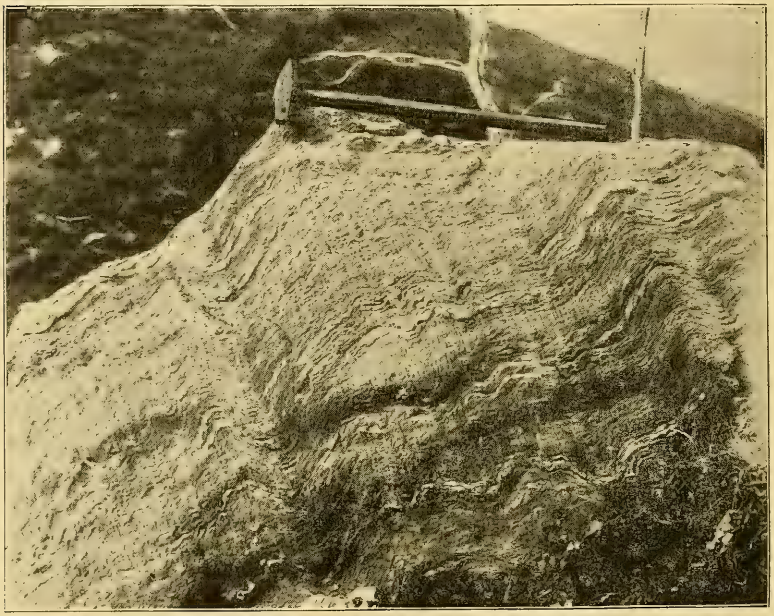

FIG. 1. Initial development of strain-slip cleavage, dipping to the right in a schistose phase of the conglomerate-gneiss horizon. The fluted bedding planes are seen dipping to the left. Under the microscope the faulting of the sharp crenulations is plainly visible with secondary formation of muscovite along slipping planes.

sion of the core rocks. The Mendon series in many localities is flexed into minute puckerings and minor folds having northerly pitching axes overturned to the west. Along the western line of the folds, and in synclinal troughs, sharp crenulations are developed; on the backs of folds stretching and consequent schistosity are best shown. When the sides of the crenulations are forced to move over each other strain-slip clear-

age is produced. A beautiful example of this is seen in Fig. 1, from the schist phase of the conglomerate gneiss two miles north-east of East Clarendon, near its contact with a coarse underlying gneiss. Blue Ridge and Pico Mountains are now capped by schist produced upon the back of folds. Close folding with axes striking nearly north and south only occurs in the amphitheatre near the summit of the greatest elevations, as on Mount Holly—a hill about a mile south of the station by that name—and near the contact with the Mendon series. The rocks of the core have no presistent strike and dip, neither of schistosity nor bedding; east and west strikes are as numerous as those trending north and south and the dips are as variable. Throughout the core the gnarled and tortuous folding of the strata represents the effect produced by the operation of repeated periods of mountain-building action of enormous force, directed not always from the east and west as in the Mendon series, but from the north and south as well.

A careful study of the Mendon series recognizes but two periods of orographic disturbance, the second acting along approximately the same lines as the first. This is well-indicated under the microscope, and in the field it is beautifully shown at North Sherburne where the strike of the rock (a conglomerate) is N. 25° W.—a trend produced by the first period of folding. The schistosity of the Green Mountains traverses this obliquely, making an angle of 35°–40°, striking N. 10° to 15° E. Both structures dip easterly at a variable angle. Forces that induced the regional lamination of the range could not have produced the great variety of trend observed in the folding of the Mount Holly series. The question of difference of environment of the central or lower parts of anticlines as compared with the outer must not be overlooked. All the phenomena go to show that the superior or Mendon series was above the neutral zone and that great slipping, stretching and crumpling took place therein dependent upon position in this belt. Below the neutral zone during the folding of the Mendon series undoubtedly most of the core rocks were placed where crushing would largely

exceed shearing and the development of the regional schistosity would not be expected. It is nevertheless true that the core rocks, although as a whole more massive than the border series, have in most localities a pronounced lamination not always due to the formation of micas, as in the Mendon series, but frequently the result of a rearrangement of the chemical combinations of the rock brought about by metasomatic and dynamic agencies. This is shown by the formation of amphibolites from some basic eruptive rock and by banding produced by the parallel injection of pegmatitic veins along the schistosity. If the core rocks were below the neutral zone during the folding that induced the regional clearage in the border series, then manifestly the intricate flexing of the inferior rocks was developed before the deposition of the Mendon series; if the core rocks were above the neutral belt they should have the normal lamination and characteristic folding universally occurring in the upper series, which is not the case.

A coarse granitoid gneiss and some associated quartzose sedimentaries occurring at North Sherburne are characterized by hundreds of minute faults to the square foot, having most divergent trends. That this was an area below the zone of neutral motion, thus permitting compensation by faulting or crushing is not tenable since the rocks are not more than 300 feet below a metamorphosed conglomerate, in which no faulting of this nature has taken place. In this phenomena we have more evidence pointing to the conclusion that the core rocks have undergone many mutations not participated in by the overlying Mendon series and must therefore be separated by an uncon formity.

The conglomerate-gneiss horizon.— On the west side of the range, the Hitchcocks have colored in this horizon extending in scattered patches beneath the "quartz-rock" from Sunderland on the south to the Canadian boundary, thickening toward the north. A patch is shown at Sunderland and another at Wallingford. Beginning in the town of Ripton, if this interpretation be correct, it extends continuously across

the State. Between the areas indicated upon their map,[1] the writer has observed it or its metamorphosed equivalent, so it is known to extend in an unbroken line from near North Bennington the entire length of the State as a persistent characteristic horizon. At the Massachusetts line it is wanting where the Olenellus quartzite reposes discordantly upon a granitoid gneiss. On the east side of the range it is described by the above-mentioned authors as occurring in a narrow band running across the towns of Plymouth and Ludlow, and is correlated with the conglomerate horizon of the Rutland Valley. It is largely upon this eastern occurrence of the conglomerate that the anticlinal nature of the Green Mountains was hypothecated by them. The phenomena of stretching of quartz and gniess pebbles in this horizon and their destruction thereby, furnished the elder Hitchcock with the necessary confirmatory data for his then revolutionary ideas concerning the production of gneisses from conglomerates by metamorphism. About one mile north of Tyson's Furnace in Plymouth and on the south slope of Bear Mountain in Wallingford occur the now classical localities where the conglomerate was most carefully studied by him and where nearly all his illustrations were obtained. It is doubtful if two areas can be found in metamorphic regions where the change of sedimentary rocks to crystalline gneiss is better or more satisfactorily shown. It was with fear and hesitancy that the question of this new effect of metamorphism was discussed, but the carefully-elaborated arguments advanced show that a keen appreciation of the proper interpretation of the phenomena revealed there was felt by the author of this most valuable contribution to the science of geology.

The first area described (the Wallingford locality[2]) is situated about where the 1500 feet contour makes a sudden jog to the south. Here the elongation and flattening of the pebbles, their contorted character and the transition of the rock to gneiss are remarked upon.

[1] Opus. cit. Pl. I., Vol. II.

[2] Opus. cit., Vol. I., pp. 32 to 44.

In Rhode Island the Newport conglomerate with its indented and elongated pebbles was a starting point in the series of changes from an unchanged conglomerate to a gneiss, the Wallingford conglomerate being an intermediate stage of metamorphism, while the Plymouth occurrence represented the completed alteration.

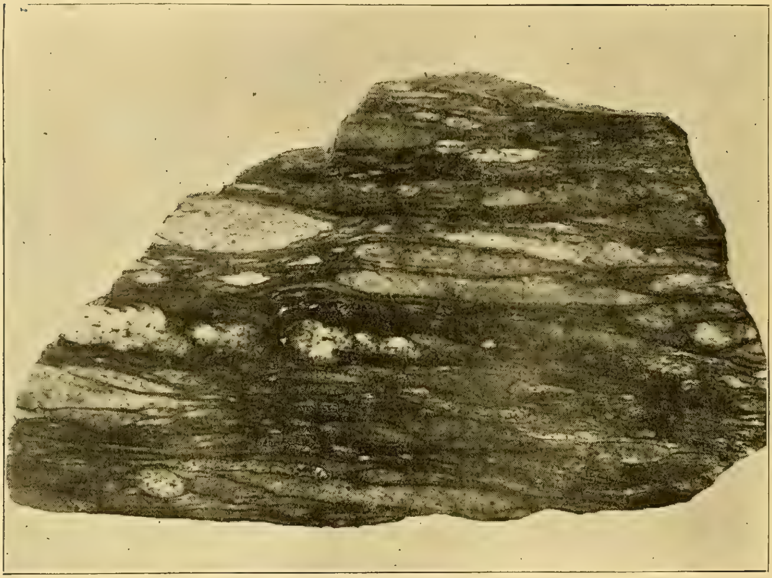

FIG. 2. Longitudinal cross-section of stretched conglomerate-gneiss. The pebbles in the upper half of the figure are mainly gneiss. In the longest pebble near the center the original lamination can still be made out. The more feldspathic clastics are now seen as thin linear films of crushed quartz and feldspar between more resistant pebbles of quartz and quartzose gneiss. From Edward Hitchcock's Green Mountain locality, one mile north of Tyson's Furnace, Plymouth, Vt. Size of block photographed 13 x 8 inches.

Much more interest was felt in this last-discovered locality where gneissic and quartz pebbles are flattened and pulled out into alternating, non-persistent bands of these minerals in a highly sugared condition, but still clearly possessing their deformed clastic outlines. Although not directly pertinent to the subject of this paper, it seems desirable to reproduce here a photograph of a block of this conglomerate, cut in longitudinal cross-sec-

tions, now in the geological exhibit of the Agassiz Museum, Cambridge, Massachusetts, Fig. 2. A fair percentage of the pebbles are of a composite nature (gneiss) and as would be expected, they have yielded most easily to the deforming forces. They now form in large part with secondarily-developed green muscovite, feldspars and cement of the pebbles, the more schistose folia of the rock. Stretching and flattening have resulted from a force operating along the plane of bedding in the direction of dip. The pebbles have been elongated most in an east and west direction, and their perceptible flattening indicates that this elongation took place under enormous load ; an environment unlike that of the pebbles at South Chittenden, which have undergone elongation without marked lateral yielding. The environment factors here were probably extreme load, a force tending to push the rock as a whole towards the west, and the presence of water charged with inorganic compounds that promoted the alteration of the clastic feldspar material, already weakened by sub-aërial decay to more stable compounds under the changed environment, and at the same time cementing the mosaic of quartz and feldspar grains resulting from the enforced granulation into a coherent rock. It seems unnecessary to postulate a high degree of temperature to account for these phenomena ; nor has plasticity, as properly defined, played any part in the deformation of the quartz and gneissic pebbles.

At North Sherburne a conglomerate occurs of considerable thickness and extends south to Ludlow, a distance of twenty-five miles. It is fully as persistent on the east side of the range in the area under discussion, as on the western, and, although some phases are unlike the western belt as a whole, it may be safely correlated with the conglomerate-gneiss horizon making, as first suggested by Adams, an anticlinal axis between Plymouth and Rutland valleys.

The question of the relations of the conglomerate-gneiss to the lower or Mount Holly rocks, has been most carefully studied on the western side of the range where the country is more open. At East Clarendon ; just north of South Chittenden, and at Hitch-

cock's Bear-Mountain locality, are three of the most instructive sections, where the contact relations of the two series are shown. All these sections show the relations of the two series in apparent *structural* conformity brought about by dynamic movements exercised throughout the rocks as a whole, but having a maximum obliterative effect immediately at the base of the conglomerate, since at this point the underlying rocks were best conditioned to record such action. Speaking of the transitional beds on Hoosac Mountain, between the Lower Cambrian quartzite-conglomerate horizon and the granitoid gneiss, Mr. Pumpelly writes as follows:[1] "This unabraded zone of crystalline rock," (reference is made here to the zone of semi-disintegrated rock on which the conglomerate was deposited unconformably) "which had its rigidity weakened by beginning disintegration, would, under folding, pressure, and metamorphism, show on the one hand a perfect and true transition into the parent crystalline rock, and on the other hand pass into the much younger beds through the similarity of the constituents derived from it; and an apparent conformity would be forced upon the whole series, and the time break would be masked by the foliation induced by the shearing action due to a slipping movement." An interpretation which so satisfactorily accounted for the transition obtaining on Hoosac Mountain can be as well applied to the transitions in Vermont at the base of the conglomerate, only here the terranes below are of a very variable character, and in a great part were already possessed of a gneissic habit which by rearrangement would even more readily take on the lamination of the rocks above. Wherever the conglomerate gneiss is found on the west side of the range a perfect transition to the lower rocks always exists, and all evidence of a discordance, such as obtains in more modern rocks of necessity must have been obliterated. It is thus seen that criteria applicable for the detection of more recent time-breaks have but little value where the rocks have been subjected to such powerful and repeated orographic disturbances,

[1] The Relation of Secular Rock-Disintegration to Certain Transitional Crystalline Schists, R. Pumpelly, Bull. Geol. Soc. of America, Vol. II., p. 215.

unless the conglomerate itself be taken as sufficient proof of an unconformity.

A practical difficulty was first met in finding a source for the abundant pebbles of blue quartz which occur so plentifully in the rock, and although sources for them are known, the proportion of such material seems to bear no proper relation to the known extent of rocks in the Mount Holly series that would be likely to yield pebbles of this mineral. Reference has already been made to a coarse phase of the conglomerate near South Chittendon where its clastic quartz best deserves the name of boulders. Such coarse phases are exceptional. An unusually coarse variety occurs one mile north of Mendon village. With the quartz pebbles there is a plentiful sprinkling of gneiss pebbles, varying in size from small grains up to two feet in diameter. Clastic areas of orthoclase are also numerous; pebbles two inches in diameter being the largest. Under the microscope abundant small grains of detrital feldspar can be detected. At this locality the original character of the rocks seems best preserved of anywhere that it is known to me, and a careful comparison of its gneissic clastics with the gneisses of the lower series immediately subjacent was made in hopes of being able to refer the pebbles to their sources. Macroscopically there appears to be no doubt that most of the pebbles were derived from the complex of gneisses to the east, and in the days before microscopical methods were used such a source would have been unhesitatingly affirmed. But today the microscope instead of simplifying one's difficulties apparently only adds to them. It is seen that the conglomerate here has recorded the evidence of dynamic action to a somewhat less extent than in many localities, but still an evident effect of metamorphism is observed. The micro-study of the lower gneiss shows them to be coarse to fine, irregularly-laminated orthoclase rocks in which both quartz and feldspar are badly crushed and distorted. About the resulting mosaics have been developed abundant epidote and titanite crystals and patches of biotite, colorless muscovite and chlorite. In the clastic gneiss little or no epidote or titanite can be detected, while there is always present more or less pale-green

pleochroic muscovite, that characterizes the conglomerate-gneiss horizon and give to it its greenish color, the result of alteration of a potassium feldspar during dynamic movement. Its other constituents seem to be identical with the neighboring gneisses, but on so slim a basis it is not deemed safe to refer the clastics to any particular gneiss area in the Mount Holly series. The feldspar clastics appear to have been derived from the pegmatite veins that are very abundant in the lower rocks to the east.

The Bear Mountain locality in some respects is more important in its bearing on the question of non-conformity than the one above described; no one area furnishes the data for all the conclusions to be drawn from the horizon. Attention was first called to the abundance of small clastic pebbles of feldspar occurring there, by Edward Hitchcock in 1861,[1] and in 1891, by Mr. Wolff.[2] As remarked by Mr. Pumpelly,[3] there seems to be "no other source than the débris of the deeply decayed Mantle" on which the conglomerate was lain down, and as such they point to a land surface close at hand where sub-aëreal decay had weakened the cohesion of the rocks, permitting a positive movement of the sea to build the more superficial mantle containing the feldspar grains, and a lower semi-disintegrated zone of gneiss and loosened blocks of gneiss into a conglomerate. The phenomenon of false bedding is well shown here, and was figured by Hitchcock[4]; transitions from coarse sediments, when the pebbles of quartz attain a diameter of nearly a foot, to fine material, point to the ordinary conditions obtaining along our coast. So, too, the outlines of the clastics are those that are characteristically produced by wave action, unless deformation has taken place, which is usually the case at this locality. All these facts are subordinate in their value compared to the conclusion to be drawn from the conglomerate-gneiss horizon as a whole, extending as it does across the State of Vermont, and presenting in one

[1] Opus. cit. p. 34.

[2] Metamorphism of Clastic Feldspar in Conglomerate Schist. Bull. Comp. Zoöl., Vol. XVI., pp. 173 to 183.

[3] Opus. cit., p. 211.

[4] Opus. cit., p. 32.

place or another all the eminent characteristics of a basal conglomerate.

An apology may be in order for dwelling so long upon the evidence detailed in support of the conclusion that an unconformity occurs at the base of the conglomerate, when, to many, the evidence afforded by the conglomerate alone would he considered amply sufficient; but in an area so greatly disturbed and metamorphosed as this, it seems best to enumerate all possible criteria that can be legitimately advanced tending to sustain the above conclusion.

SUMMARY.

To summarize briefly, this paper is hoped to have substantiated essentially the following facts:

1. That immediately beneath the Lower Cambrian quartzite in Vermont there is a series of more or less metamorphosed clastic rocks of no inconsiderable thickness; the upper member of this series being a dark chloritic mica schist; the lower member a highly metamorphosed conglomerate, and between these several pebbly limestones and pebbly micaceous quartzite strata. Evidence for and against an unconformity at the top of the schist is presented, but no satisfactory data are advanced to sustain either interpretation. The evidence for a time-break at the base of the conglomerate is thought to have been established, and the data in support of this conclusion are discussed in some detail. These rocks are referred to the Algonkian Period and are provisionally called the Mendon series.

2. That below the Mendon sedimentary rocks, a still older, more metamorphosed and more variable series of stratified rocks of Algonkian age occurs, together with gneisses and schists, whose origin is unknown, and abundant metamorphic equivalents of old basic igneous rocks. Many of the varieties of rocks occurring in this series are enumerated, and, together with their structure are contrasted with the rocks of the Mendon series, whose basal member, the conglomerate, delimits the series above. From their typical development in the town of Mount Holly, Vt., it is suggested that these rocks be called the Mount Holly Series.

CHARLES LIVY WHITTLE.

Editorials.

The protracted ill health of Major J. W. Powell has led to his resignation of the office of Director of the United States Geological Survey, and to appointment, with his hearty endorsement, of Professor Charles D. Walcott who has had charge of much of the executive work of the Survey for the past year or more. Although Major Powell has suffered much from other forms of ill health for several years, the immediate cause of his resignation, we understand, was a renewal of trouble from his amputated arm, which had reached a stage requiring re-amputation. As is well known, Major Powell lost his right arm on the evening of the first day of battle at Shiloh, while he was gallantly trying to hold his battery's position till night should come to the relief of the sorely pressed army. We are glad to learn that the re-amputation has already been successfully performed, and that there is every prospect of a speedy recovery. The probability of a measurable restoration to health has been regarded sufficient to warrant Major Powell in retaining the less exacting directorship of the Bureau of Ethnology, and to give encouragement that he may be able to finish the important ethnological studies upon which he has been engaged for several years. It is earnestly to be hoped that this may be realized, and that he may be permitted to add to his record as an executive the more distinctively scientific fruits of a very original and philosophical mind.

The appointment of Mr. Walcott meets with the hearty concurrence of his associates, and will be approved, we are sure, by scientific men generally. Though a comparatively young man, he has shown both investigative and executive ability of an unusual order and possesses in high degree the personal qualities which the position requires.

Major Powell's administration has been a very notable one, and will doubtless stand forth even more distinctively as we recede from it in time and see it in perspective when its greater outlines will be better defined and its details will fall into their places as parts of the whole. From a comparatively small corps of workers, with an inadequate appropriation, trammeled by legislative restrictions and uncertainties, and embarrassed by untoward inheritances from three inharmonious territorial surveys, the organization has grown to be perhaps the largest and most productive of official geological surveys. Its very strength has indeed been an occasion of criticism on the part of some who have conceived themselves to be unfavorably affected by its great influence.

One of the most notable characteristics of the administration has been the large consideration given to the differentiation of investigative work. To a degree perhaps never before equaled in governmental work facilities have been afforded for the careful and broad investigation of special subjects of a fundamental nature. A portion of the results of these studies have appeared in the special papers of the annual reports, in the monographs, and in the correlation papers, but a considerable portion are yet to be issued.

Externally, perhaps the most conspicuous feature of Major Powell's administration has been the great prominence given to topographic work. If this work be conceived as subserving no other function than that to which topographic maps were usually put previous to the current decade, it might well be doubted whether so large a proportion of the resources at the command of the Survey were wisely given to this part of the work, and the question of ratio and proportion may be a pertinent one in any case, but it is necessary to a proper interpretation of the policy of the Survey to note that an important evolution of geological science has been in progress, and that topographic and physiographic factors now play a part in good geological work that they have never played before. Physiographic geology has had a new birth, and has taken an important place among the

essential branches of the science. Major Powell has himself, as an individual investigator, been one of the pioneers in this new departure, and the doctrine of the base-level, which we owe so largely to him, taken with its corollaries, constitutes one of the most important contributions of recent decades. In so far as the topographic work of the Survey has become an adjunct and antecedent of the new physiographic phases of geology, it merits the highest commendation. In so far as it has fallen short of this, it perhaps expresses the practical difficulty of at once rendering topographical work *geological*, a difficulty not to be wondered at since topographical work has been so largely regarded as a function of some other science than geology, some science in which the mere hypsometrical factors of relief, mechanically represented, have been chiefly considered instead of the genetic factors that give meaning to the topography. Until a generation of *geological* topographers can be trained up, topographic work cannot be expected to be other than mechanical and relatively expressionless. It may be questioned whether some of the topographic effort that has taken the *extensional* form might not better have taken an *intensive* form in the interest of transmuting mechanical topography into geological topography, or, in other words, the substitution of genetic expression for meaningless mechanicalism. But, withal, the great development of the topographical side of the Survey has been in the line of progress and the needed transformation in the fundamental nature of the work should grow out of it through persistence in the educative process already begun. We have no sympathy with the geologist who looks upon topographic work as an alien function to be performed by those whose profession does not lead them to know how topographic relief was produced or what it means, and who carps at the Survey for an alleged invasion of fields outside its domain.

Under Major Powell's administration, the physical and philosophical phases of the Survey have received a more marked impetus than the palæontological, though an able and active corps of palæontologists have always formed a large division of the

staff, and have made most important contributions. This ratio of development has been, perhaps, duly proportionate to the demands of the growing science, for the palæontological side of the governmental work was previously, we think, the more advanced and occupied a relatively larger part, and might well advance less rapidly and permit the physical wing to come abreast of it.

The administration has had a good degree of success in the very delicate and difficult task of coördinating the work of the general government with that of the states and in securing friendly and helpful coöperation. Very notably excellent results are being worked out by the joint effort in some cases.

Not to unduly lengthen this notice by dwelling upon other salient features of Major Powell's administration, suffice it to say that it has been marked by originality and boldness of conception, by good judgment in organization, by unusual skill in securing favorable legislative action, by large liberty to colleagues in the prosecution of their work and the publication of their results, by broad and comprehensive views of the functions of the Survey, and by great courage and tenacity of purpose in the endeavor to compass them.

The administration goes into the hands of a chosen colleague in whom the retiring Director will find a worthy successor. We predict for Mr. Walcott a brilliant administration. T. C. C.

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We very much regret that the difficulties connected with the Missouri Geological Survey, to which we have once before made allusion, culminated recently in the abrupt termination of Mr. Winslow's directorship. This unfortunate result finds some mitigation, however, in the fact that the Survey is not altogether to be abandoned, as seemed at one time not unlikely, and that it has been placed in so excellent hands as those of Dr. C. R. Keyes, of the Iowa Geological Survey. It is also gratifying to learn that Mr. Winslow has been engaged to complete his report on the lead and zinc deposits, and that thus a very important

part of the Survey's work will be saved from loss, though the report will doubtless not be brought to the degree of completeness it would have reached under better conditions.

Dr. Keyes will be embarrassed at the outset by severe financial limitations, but we trust that his abilities and tact will win a large success in the end.

T. C. C.

Reviews.

The Lafayette Formation. By W. J. McGee. Twelfth Annual Report of the U. S. Geological Survey, pp. 347-521, 5 maps, 5 plates, 45 text cuts.

This brochure almost opens a new chapter in geological history; for although the formation is essentially a surface feature over an area of 100,000 square miles, and only thinly-covered by a mantle of Columbia sands extending over another 150,000 miles, yet the knowledge of these deposits was fragmentary, and they were not correlated as a unit—or interpreted in their bearing on the physical history of the continent, until the appearance of this work.[1] The investigation of the formation was commenced in Mississippi by Professor E. W. Hilgard, who gave it the above name, though the later appellation of "Orange Sand," given by Professor J. M. Safford, in Tennessee, was commonly accepted. Subsequently, McGee's researches along the Atlantic border made known the Appomattox formation, which the author afterwards found to be a northern continuation of Hilgard's Lafayette, or the "Orange Sand." Confusion also arose in the application of the latter name, and by consent of all the authors, Hilgard's original name was adopted.

The report is written in a narrative form in only a few chapters, which are unfortunately not sufficiently subdivided under topical headings to make the arrangement most favorable as a work of reference. On the other hand, the set of maps is particularly clear and explanatory of the text.

"The Lafayette formation may briefly be described as an extensive sheet of loams, clays, and sands of prevailing orange hues, generally massive above, generally stratified below, with local accumulations of gravel along the water-ways", (p. 489). The physical structure is peculiar, although the deposit resembles certain residuary clays derived from the Archean, and from lower Paleozoic limestones, from which it is not always easily distinguished when the gravels are absent, while the gravels

[1] The author had published several advance notices prior to the appearance of the present report.

may resemble those of the sometimes-underlying Potomac, or Tuscaloosa series. Again, the physical features of the whole formation are often reproduced in the overlying Columbia formation. Although the Lafayette is remarkably persistent in its characters over the enormous area, yet care must be exercised in its study. In exposed sections, the surfaces become case-hardened, and stand as vertical walls, on which often the shades of ferruginous oxidation can be seen. The subjacent formations give rise to local variations in the amount of sand, clay, or calcareous matter, which is particularly shown in the agricultural features. This formation once covered the entire coastal plain of both the Atlantic and Gulf margins from Maryland to Mexico, and extended up the Mississippi embayment as far as the mouth of the Ohio, covering a belt extending from the sea margin 50 to 200, or even 500 miles into the interior of the continent. Often, the deposits form only a thin mantle, and away from the valleys ten or twenty feet may be regarded as an average thickness. In the valleys, the accumulations reach 120 feet, and toward the mouth of the Mississippi, 200 feet or more. But the formation has been degraded to an enormous extent by erosion, which has removed it from broad areas, leaving only patches to mark its former extension.

In an introductory chapter, the author has given us an excellent description of the physiography of the coastal plain and of the various geological series in contact with the Lafayette formation. On the Atlantic border, the interior of the coastal plain is sharply defined by the margin of the Piedmont plateau, generally characterized by Archean rocks. This margin is the "fall line," or location of the last great rapids in the descent of the rivers to the sea. Below this line, the streams, which generally cross the plains, are more or less navigable. The interior margin of the Gulf coastal plain is less sharply defined, as it trends across the termination of many different formations of varying characteristics. This same coastal plain extends seaward to the margin of the continental shelf, which is now submerged and extends far seaward of the present coast.

The geology of this plain presents a varied study. Generally speaking, the Potomac (or Tuscaloosa) or later Cretaceous deposits form the interior margin of the belt. This basement is succeeded by many stages of the higher Cretaceous, Eocene, and Miocene accumulations, although the succession is not everywhere complete. No marine fossils higher than the middle Miocene are known on the

coastal plain, except at two or three localities. The topography of all of these formations was greatly modified by erosion during intervening periods of high level of the land, but in general, the successive formations were planed nearly to base level before the succeeding deposits were laid down. This was the condition before the Lafayette epoch, and the seaward slope of the country was more gradual than at present, although the continent was high enough to allow the submerged continental shelf to be a sub-aërial plain. Then came the extensive subsidence and seaward tilting, which allowed the invasion of oceanic waters over the coastal plain, so as to permit of the deposition of the loams even upon the margin of the Piedmont plateau. This subsidence was unequal, least in the region of Cape Hatteras, greater along the South Carolina axis, again diminished in the Gulf region, and greatest along the Rio Grande. The author regards all of these Lafayette deposits as having accumulated at sea level from the land wash brought down by the rivers. Although devoid of marine life, so far as known, this seems the most rational explanation, although the physical characters are very different from those of the earlier Tertiary or Mesozoic deposits, which were laid down after submergence with less decided seaward tilting.

Mr. McGee regards the duration of the epoch of subsidence as short. The succeeding elevation, which carried the country from 100 to 1,000 feet above tide, he regards as much longer. This uplift was not uniform, probably only 100-300 feet at Cape Hatteras, and 1,000 feet at the mouth of the Mississippi, but in undulations such as characterized the previous subsidence; where the greatest depression had taken place, there the greatest elevation followed along the same axes. Moreover, it is apparent from the intensity of erosion that the elevation was greater along the Appalachian and Cumberland plateaus than along the coast, giving greater slope to the rivers than at present. This elevation was unquestionably of long duration and the erosion enormous, removing from the valleys a large proportion of the accumulations of the preceding epochs and cutting through them to depths of 150 feet and upward, and to widths of 10 and 20 miles, even 100 miles in the case of the Mississippi. This the author emphasizes, giving great prominence to the geomorphy from which the post-Lafayette elevation is deduced.

After this long-continued period of degradation, the continent subsided, but not so much as during the Lafayette days, and during

this subsidence the Columbia formation was deposited. Some of its characters are similar to those of the Lafayette, and indeed the latter deposit may often be mistaken for the earlier, where unconformity is not apparent. The Columbia formation covered the lower half of the coastal plain, and partly filled the great valleys which thus became estuaries. These deposits form the "second bottoms" of many of the coastal rivers, particularly on the Gulf slope. In short, the Columbia formation of the South is largely the Lafayette made over, though in the North its materials grade into those of the glacial period.

Following the Columbia submergence the continental margin again rose, even to an altitude above that of modern times, to such an extent as to permit of the clearing out of the valleys to a considerable extent; including those now submerged along the oceanic plateau. Then followed a subsidence to modern conditions. This post-Columbia elevation did not last nearly so long as the post-Lafayette, for 90 per cent. of the accumulations still remain.

The altitudes at which the Lafayette deposits are now found vary. In Maryland they occur at 500 feet; southward they decline so that at Hatteras they occur at 100–200 feet. Along the axis of greatest oscillation in South Carolina the formation rises to 800 feet, but again descends southward so that north of Mobile Bay they rise only 500 feet above tide. Again in Illinois and Arkansas, the loams rise to only 350 and 250, whilst they culminate at 1,000 feet along the Rio Grande. But as river terraces of the streams emptying into the Lafayette sea, the reviewer has met with the extension of the formation in the southern Appalachian at 1,500 to 2,000 feet, thus supporting the author's conclusions as to the greater magnitude of terrestrial undulation in the mountain regions than along the coast.

At Cape Hatteras, the Columbia deposits now rise only 25 feet above tide, but they increase to 300 feet in altitude to the north and again southward, so that in South Carolina they rise to 650 feet. Again they decline to 25 feet above the Gulf in Mobile Bay. Farther southwestward their present elevation is from 100 to 200 feet.

The meager flora of the Lafayette has both Cretaceous and Pleistocene features, and the more meager fauna represents the entire Neocene. The Columbia is regarded as the earliest Pleistocene, and the Lafayette as the later Pliocene, though the author groups it with the Miocene and small areas of marine Pliocene, the whole making the American Neocene. Its biological relations are not known; it is by

its physical characters that the Lafayette formation has been investigated and largely explained.

The author of "The Lafayette Formation" has made one of the most important recent contributions to geological science. Besides his contribution to the geology of an enormous area, the principles of geomorphy are emphasized, and the interpretation of the continental changes of the later Tertiary days are set forth in an original manner, forming one of the most interesting chapters in dynamical geology.

The maps are particularly worthy of attention. The first represents the physiography of the coastal plain, and its relations both with the higher land area and deeper oceanic depression. The next is a colored map showing the distribution of the Lafayette formation and the overlying Columbia. The third map shows the continental area during the Lafayette subsidence; it is both a topographical and hydrographical chart of the physical features of land and sea when 250,000 square miles of the southeastern part of the continent was submerged. It is of special interest. Then follows the topographical map of the high continent during the post-Lafayette elevation, when the continental region was expanded by 100,000 miles or more in excess of that of modern times. The last map shows the continental contraction during the Columbia period—and a very strange looking map it is with the land margin dissected by numerous estuaries, scores or hundreds of miles in length, resulting from the submergence of the great valleys of the south in connection with the tilting of the land toward the South Carolina axis of oscillation.

Although this work was commenced by others, yet the extension and digestion of the whole belongs to the author, and it is a remarkably meritorious work. But in the study of geomorphy, and of the most interesting continental changes, the work is almost entirely original. The whole forms one of the most complete, yet peculiar, chapters of American geology. This review is only sufficient to call attention to a very suggestive report in which, however, there are still some questions left open. The author is to be congratulated on having taken up such an important and interesting but little known subject, and for working it out to such a degree of completion.

J. W. SPENCER.

Elementary Meteorology. By WILLIAM MORRIS DAVIS, Professor of Physical Geography in Harvard College. Boston, U. S. A. Ginn & Co., Publishers, 1894, pp. XII.+355.

THE announcement, made some months ago, that Prof. Davis was about to publish a work on meteorology, was hailed with satisfaction by all those interested in this branch of natural science. The book, which has recently been issued by Ginn & Co., presents the condensed results of the author's reading, observation, and teaching during the last fifteen years. Since it has been prepared by one who is not only eminent as an original investigator, but also as an experienced teacher, it is scientific in its treatment, fully in accord with the latest advances in meteorology, and, at the same time, well fitted for the use of college students of the more advanced years. In so far as the experience of the writer goes, this book would seem to be better adapted to the abilities of juniors and seniors of the majority of our colleges than to the "later years of a high-school course, or the earlier years of a college course," as the author suggests in the preface.

The plan of the book is stated by the author at the outset, as follows: "The origin and uses of the atmosphere are first considered, with its extent and arrangement around the earth. Then, as the winds depend on differences of temperature over the world, the control of the temperature of the atmosphere by the sun is discussed, and the actual distribution and variations of temperature are examined. Next follows an account of the motions of the atmosphere in the general and local winds; in the steady trades of the torrid zone, and in the variable westerly winds of our latitudes. The moisture of the atmosphere is then studied with regard to its origin, its distribution, and its condensation into dew, frost, and clouds. After this, we are led to the discussion of those more or less frequent disturbances, which we place together under the name of storms; some of them being large, like the great cyclones or areas of low pressure on our weather maps; some of them very small, like the destructive tornadoes. The effect of these storms and of other processes in the precipitation of moisture as rain, snow, and hail is next considered. Closing chapters are then given to the succession of atmospheric phenomena that ordinarily follow one another, on which our local variations of weather depend, together with some account of weather prediction; and another on

the recurrent average conditions that we may expect, in successive seasons, repeated year after year, which we call climate."

The above statement gives an idea of the scope and method of treatment of the subject. There are a few points, however, which deserve more particular mention. In chapter III., the distribution over the earth of the insolation, or radiant energy received by the earth, is discussed, and by means of a very ingenious diagram, the amount of insolation for all latitudes for each month of the year is graphically shown. A detailed discussion of the various processes of absorbtion, conduction, radiation, and convection, by means of which the atmosphere gains and loses heat, is given. In the course of this the author takes exception to the statement, so common in most physical geographies, in which the atmosphere is "compared to a trap which allowed sunshine to enter easily to the earth's surface, but prevented the free exit of radiation from the earth." In reality, the coarse-waved radiation from the earth passes out readily without great absorbtion, either by the clear air or the water-vapor, which has been proved to be as poor an absorber as pure dry air.

Again, the exact processes, by which convectional circulation is set up, are clearly brought out, and the incorrectness of such loose statements, as "the air is heated and rises, and the cold air rushes in from either side to fill the vacuum thus formed," is emphasized.

A general review of the distribution of pressures and the circulation of the winds shows the student two particulars, in which the expected arrangement of pressures and motions according to the theory of convection, as applied to the origin of winds, are contradicted by the facts. The polar pressures are high, not low, the highest pressures occur around the tropics, where intermediate pressures were expected, and the winds do not follow the gradients, but are systematically deflected. Either the convection theory is fundamentally wrong as an explanation for the winds, or it needs to be supplemented by some factors up to this time unconsidered. This fact the author brings clearly to the mind of the pupil, who is then led to see that, perhaps, the oblique course of the winds may account for the distribution of pressures at the poles and the tropics. The cause of the oblique course is found in the deflecting influence of the earth's rotation. It is proportionate to the velocity of motion, and increases from zero at the equator to a maximum value at either pole, but it does *not* depend upon the direction in which the body is mov-

ing. In this connection, the author points out another error found in many text-books, namely that the oblique course of the winds is due to a lagging behind, as they move from regions of less to those of greater rotary velocity, and, therefore, that winds traveling due east would not be deflected at all. As was clearly shown by Ferrel, many years ago, both the explanation and its corollary are wrong, although they have appeared in many text-books, even of recent date.

Following the discussion of a competent theory for the general circulation of the winds, there is given a systematic account of the different members of the circulation, and a classification of winds according to cause into (1) planetary, (2) terrestrial, (3) continental, (4) land and sea breezes, (5) mountain and valley breezes, (6) cyclones and other storms, (7) eclipse winds, (8) landslide and avalanche blasts, (9) tidal breezes, (10) volcanic storms.

Chapter X., treating of cyclonic storms and winds, is one of the most interesting and valuable in the book. The tropical cyclones are first considered. The evidence of convectional action in these cyclones is considered, and it is shown that their distribution both in time and place points strongly to the theory that they originate through the overturning of great masses of air, due to unequal heating. But it is clearly pointed out to the pupil that it has not yet been directly shown that the temperature of the cyclonic mass is higher than that of the surrounding atmosphere at corresponding altitudes, a condition which, of course, must be satisfied before convection can take place. If this shall, hereafter, be shown *not* to be the case, the convectional theory will have to be abandoned.

In points like this, Prof. Davis' book is particularly good, for, all along, he has stated clearly not only what is certainly known, what is probable, and what is doubtful, but also what is not known. This prevents the student from forming misconceptions of the subject, or dropping into loose habits of thought.

The extra-tropical cyclones are closely compared with the tropical cyclones, and their points of likeness and difference shown. Two theories for their origin are discussed, and lines are indicated along which the rival theories may, some day, be tested, but here again, the fact is emphasized that much is not yet known, and that positive didactic statements are to be avoided.

Space will not permit even a brief mention of many other points to which we should like to call attention. The subjects of thunderstorms,

rainfall, weather, and climate receive careful consideration. The text is illustrated by many maps and diagrams, of which a number are original. The generalized charts, showing the winds of the Atlantic and Indian Oceans, taken from the atlas of the German Naval Observatory, are particularly valuable. But a few of the diagrams, although showing clearly what they were intended to represent, fall short of the standard of artistic excellence set by the others.

The value of this book lies, if in some things more than in others, in the logical treatment of the subjects, the frequent turning aside from the discussion for the purpose of introducing additional facts in order to correct, modify or substantiate hypotheses, and the clear discrimination, between facts, well-established theories, and working hypotheses. The pupil, who uses this book intelligently, will learn, not only many things about meteorology, but what is far more valuable, true scientific methods of thought, study, and work.

HENRY B. KÜMMEL.

Analytical Abstracts of Current Literature.

SUMMARY OF CURRENT PRE-CAMBRIAN NORTH AMERICAN LITERATURE.[1]

Lawson[2] gives a résumé of the geology of Northeastern Minnesota adjacent to Lake Superior. Surrounding the Lake there are four geological provinces, from the top downward, the Potsdam, Keweenian, Animikie, and Archean.

The Rocks of the Potsdam are flat-lying shaly sandstones, generally of a red color.

The Keweenian occupies the entire Minnesota coast from Duluth to Grand Portage. The series consists in this area of a well stratified series of volcanic flows, having a gentle lakeward dip, which does not generally exceed 10°. The sedimentary formations are represented in the series, but occupy less than one-half per cent of the coast line. The lavas are largely vesicular or amygdaloidal in character, and in those of acid composition in which the vesicular structure is not so well developed are numerous irregular joints. The series has been invaded by many later intrusive masses, which occur as nearly vertical dikes, or more commonly as injected sills which coincide with the planes of stratification of the bedded flows. Since the time of the outflow of the Keweenian rocks, the strata have suffered comparatively little disturbance, the prevalent lakeward dip being probably due to the attitude of the slopes upon which the lavas flowed, rather than entirely to a differential movement of once horizontal strata. The pre-Keweenian labradorite rocks exposed at a number of points were profoundly eroded before the Keweenian was deposited upon them, and they were presumably Archean.

The Animikie rocks occupy the shore of the Lake from Grand Portage to Port Arthur. The series is composed altogether of sedimentary strata, and consists mainly of fine-grained sandstones, which are locally quartzites, carbonaceous shales or slates, and in small part of cherts and jaspers, beds of carbonate of iron, hematite and magnetite, conglomerate, and occasional lenses of non-ferruginous carbonate in the slates. Except in local instances

[1]Continued from p. 118.

[2]Sketch of the Coastal Topography of the North Side of Lake Superior with Special Reference to the Abandoned Strands of Lake Warren, by A. C. Lawson. In 20th Annual Rep. Geol. & Nat. Hist, Sur., Minn. pp. 181-289.

the rocks have been disturbed very little from the horizontal, the average dip of the strata being in a southeasterly direction at an angle probably not exceeding 5 degrees. Intrusive rocks are abundantly present as sills lying parallel to the stratification, resembling contemporaneous beds, and as vertical dikes, some of which have been observed in continuity with the sills. Faulting is a common occurrence in the Animikie, many scarps being due primarily to this cause.

The Archean shares the coast line with the Animikie and Keweenian from the vicinity of Port Arthur to the eastern end of Nipigon Bay, and beyond this point to the outlet of the lake is the dominant series. This complex consists of two divisions: 1) a great volume of profoundly altered sedimentary and volcanic rocks, characteristically schistose or in the form of massive greenstones, which have suffered intense disturbance, and which correspond to what has been designated the Ontarian system, and 2) immense batholites of irruptive gneiss and granite, which have invaded the rocks of the Ontarian system from below in the most irregular fashion, corresponding to that division of the Archean which is commonly recognized as Laurentian. These Laurentian rocks exhibit only to a very subordinate extent those evidences of disturbances and deformation which are so abundantly apparent in the schists which they have invaded. The Laurentian gneisses and granites occupy much more of the shore than do the metamorphic and schistose rocks of the Ontarian. Both divisions of the formation are cut by basic dikes, which, as a rule, do not exceed 100 feet in width, and are vertical or nearly so. The Archean forms the basement upon which the Animikie rests in glaring unconformity, the actual superposition being observed at several points, with the Keweenian lying flat on the latter. Very frequently, however, the Keweenian reposes directly upon the Archean.

Van Hise[1] gives an historical sketch of the Lake Superior region to Cambrian time. The five divisions of this region are the Basement Complex or Archean; The Lower Huronian, Upper Huronian and Keweenawan, the last three together constituting the Algonkian, and the Lake Superior Cambrian Sandstone. Each of these divisions are separated by unconformities.

The Basement Complex consists mainly of granites, gneissoid granites, and of finely foliated dark colored banded gneiss or schist. The relations which obtain between the two divisions are frequently those of intrusion, the granites and gneissoid granites being the later igneous rocks. There is no evidence that any of the dark colored schists are sedimentary, but it is certain, if a massive granular structure be proof of an igneous origin, that a part of them are eruptive, for between the two are gradations.

[1]An Historical Sketch of the Lake Superior Region to Cambrian Time, by C. R. Van Hise. In JOURN. OF GEOL., Vol. I, No. 2, pp. 113-128. With geological map.

The well known characteristic rocks of the Lower Huronian are 1) conglomerates, quartzites, quartz-schists, and mica-schists, 2) limestones, 3) various ferruginous schists, 4) basic and acid eruptives, which occur both as deep seated and as effusive rocks. The order given, with the exception of the eruptives, is the order of age from the base upward. In the Lower Huronian are placed the Lower Vermilion, Lower Marquette, Lower Felch Mountain, Lower Menominee, the cherty limestone formation of the Penokee district, and also probably the Kaministiquia series of Ontario, and the Black River Falls series of Wisconsin.

The formations of the Upper Huronian are 1) a basement slate and quartzite, frequently bearing basal conglomerates, 2) an iron-bearing formation, consisting originally of lean cherty carbonate of iron, calcium and magnesium, and 3) an upper slate. Associated with the sedimentaries in the Michigamme, Crystal Falls, and other districts, are great volcanic series, comprising greenstones, agglomerates, greenstone conglomerates, volcanic ash, and amygdaloids. Where these occur the orderly succession is destroyed. Included in the Upper Huronian are the Penokee, Mesabi, Animikie, Upper Marquette, Upper Menominee, and Upper Felch Mountain districts.

The Keweenawan consists of interstratified lavas, sandstones and conglomerates. The lavas are prevalent at the lower part of the series; interstratifications of the two occur in the middle portions; and the pure detritals exclude the volcanics in the upper portion of the series.

The Lower Huronian is largely crystalline, the Upper Huronian semi-crystalline, and the Keweenawan simply cemented. Locally along axes of intense plication, both the Lower Huronion and Upper Huronian have been transformed into completely crystalline schists. The Cambrian of Lake Superior is a horizontal sandstone, and rests unconformably upon all the preceding.

Smyth[1] describes a contact between the lower quartzite of the Lower Huronian and the underlying granite at Republic, Michigan. Below the lowest exposures of magnetite-actinolite-schist are exposures of the lower quartzite, and below this, hanging upon the northern flank of the granite, is a conglomerate containing very numerous well rounded bowlders of granite and gneiss, identical with the rocks immediatiately below. It is concluded that this conglomerate from its position can not possibly belong to the Upper Huronian, and that it is a true basal conglomerate of the Lower Huronian.

Winchell, N. H.,[2] gives the following as the general consensus of opinions

[1] A contact between the Lower Huronian and the Underlying Granite in the Republic Trough, near Republic, Mich, by H. L. Smyth, Journ. of Geol., Vol. I., No. 3, pp. 268-274.

[2] The Crystalline Rocks, by N. H. Winchell. In 20th Annual Rep. Geol. & Nat. Hist. Sur., Minn., 1891, pp. 1-28.

of several geologists as to the descending succession of the rocks of North-eastern Minnesota.

1. Keweenawan or Nipigon series unconformably beneath rocks bearing the "Dikellocephalus" fauna, and consisting of fragmental and eruptive beds, the upper portions being almost entirely red sandstones.

2. Alternating beds of eruptive sheets and fragmental rocks. The fragmentals are thin bedded slates, actinolite-schists, magnetitic jaspers, cherts and quartzites. The sheets are ordinary eruptives or pyroclastics.

3. Immense quantities of true gabbro often bearing Titaniferous magnetite, are associated with contemporaneous felsites, quartz-porphyries and red granites. This gabbro includes several masses of the next older strata, particularly the Pewabic quartzite.

4. The Animikie. This series is characterized by a great quartzite associated with the iron ores and cherts. The quartzite (Pewabic) lies unconformably on all the older rocks. It often is conglomeratic, bearing debris of the underlying formations. Within it is mingled volcanic tuffs from contemporaneous eruptions. The Pewabic quartzite includes that of Pokegama Falls on the Mississippi River, and of Pipestone County. In the vicinity of contemporaneous volcanic disturbances its grain is fine, like jaspilite, and sometimes it has acquired a dense crystalline structure from contact with the gabbro.

5. The Keewatin. This is a volcanic series of great thickness, being composed mainly of volcanic tuffs, presenting more or less evidence of aqueous sedimentation, but conglomerates, graywackes, quartzitic schists, and glossy serpentinous schists are present. The Kawishiwin formation, apparently the upper member of the series, embraces the great bulk of the greenstones, chloritic schists, jaspers, and hematites. The iron ores are in lenticular lodes, and stand upright conformable with the general position of the rocks.

6. The Keewatin series becomes more crystalline towards the bottom, and passes conformably into completely crystalline mica-schists and hornblende-schists, which are named the Vermilion series. The rocks are usually stratiform, contain magnetic iron ore, and embrace some dark massive greenstone belts, in which no stratification bands are visible.

7. The Laurentian. When not disturbed by upheaval the Vermilion schists pass into Laurentian gneiss, there being a gradual increase in the feldspathic and siliceous ingredients. Even after the Laurentian characters are apparently fully established, conformable bands of Vermilion schists reappear: from which it is plain that the base of the Vermilion is an uncertain plane, which can not be located exactly. This normal passage from the Vermilion to the Laurentian is frequently disturbed by the intrusion of numerous dikes of light colored granitic and basic rocks. These were both in a fluid state, the only non-fluid rocks being the schists which are embraced

within them in isolated pieces. In a similar manner small areas of Laurentian granite, sometimes directly in contact with the schists, have the imperfectly crystalline condition of the Keewatin.

Nos. 3 and 4 are separable from No. 2 by divergence in dip and strike, as well as by a marked difference of lithology. There is consequently some evidence of unconformity between them. Below No. 4 is a great physical break, which separates Nos. 1, 2, 3, and 4 from 5, 6 and 7 throughout the Lake Superior region. This break is the greatest erosion interval which has been discovered in Palæozoic geology. 1, 2, 3, and 4 together constitute the Taconic, Nos. 5, 6, and 7 constitute the fundamental complex or Archean, which is a unit in its grander features.

The structure and origin of the foregoing series are considered in some detail. It is concluded that stratification can always be discriminated from schistosity or slaty cleavage by the varying shades of color bands which sweep across the surface of the rocks, and by gradations in the kind and size of grains across the bands. These layers may vary from 1-16 of an inch to several inches or several feet across.

Comments.—As used by the United States Geologists, Nos. 1, 2 and 3, are included in the Keweenawan. These divisions and the break between 2 and 3 are recognized by Irving, so that the difference is merely one of nomenclature. No. 4 is Upper Huronian; No. 5 is Lower Huronian; and Nos. 6 and 7 are the Basement Complex or Archean. The break between the Lower Huronian and the Basement Complex is perfectly clear on the south shore of Lake Superior, and is found by Lawson at the base of the Keewatin in Ontario. In Minnesota, Professor Winchell, on the contrary, regards the Keewatin as grading down into the underlying series. Many geologists would disagree with the statement that stratification can always be discriminated from schistosity or slaty cleavage by either of the criteria mentioned or by both combined.

Grant,[1] in 1893, publishes his note book, made on a trip in Northeastern Minnesota. The areas visited were those of the Kawishiwi river, Snow Bank lake, Kekequabic lake, and Saganaga lake. In the study of these areas there was no evidence found of a transition from semi-crystalline and crystalline schists into granite. On the other hand, abundant evidence was found of the eruptive nature of the granite rocks into the surrounding sediments. The gneissic and so-called bedded structure in the granitic rocks is not as common as has been supposed, the structure usually being truly granitic. The Kawishiwi river and Snow Bank lake massive rocks are hornblende syenites. The Saganaga rock is a coarse hornblende granite. That

[1] Field Observations on Certain Granitic Areas in Northeastern Minnesota, by U. S. GRANT. In 20th Annual Rep. Geol. and Nat. Hist. Sur. Minn., pp. 35-110.

around Kekequabic lake is a pyroxene granite, and associated with it is peculiar pyroxene-granite-porphyry. The intrusive character of the granite is particularly well shown between Sec. 31 and 32, T. 63 N., R. 10 W., near Clearwater lake, and in the S. E. ¼ of the S. W. ¼ Sec. 26, T. 64 N., R. 9 W., on the west shore of Snow Bank lake. Along the Kawishiwi river, the rocks mapped comprise gabbro, syenite, mica-schist, graywacke, etc.; greenstone and quartz-porphyry. The gabbro is the most recent, and covers part of the older rocks. The syenite is older than the gabbro, and is younger than the greenstone and mica-schist, both of which it cuts. The mica-schists, graywackes, etc., are vertical, and have a general east northeast strike. These have been formerly mapped as belonging to the Vermilion series, but there seems to be good reason for putting all of this type of rock in the area mapped into the Keewatin. The greenstone is presumably of Keewatin age, and is probably younger than the mica-schists, graywackes, etc. Quartz porphyry dikes are found cutting the greenstones in several places, but they have not been seen in the other rocks in the immediate vicinity.

Comments.—The conclusions of this report differ from the general succession given by Professor Winchell in the fundamental point that there is no gradation between the granitic rocks and the metamorphosed sedimentary rocks. Also all of the metamorphosed sedimentary rocks are regarded as belonging to the Keewatin (Lower Huronian?) while the Vermilion schists are not found. If there now exists in this area the original basement upon which the sedimentary rocks were deposited, this has not been found. It is of course possible that such a Basement Complex does not exist in the Kawishiwi river area, the one which was most closely studied, nor even in the entire region, but this is not thought probable.

Winchell (H. V.)[1] describes the Mesabi iron range of Minnesota. The range extends from the Canadian boundary, a little south of west to the Mississippi river, a distance of 140 miles or more, but is concealed for a part of this distance by the later gabbro overflow. The succession of the Mesabi in descending order is:

1. Gabbro unconformably on all the following................Taconic.
2. Black slates Animikie..................................Taconic.
3. Greenish siliceous slates and cherts......................Taconic.
4. Iron ore and taconyte horizon...........................Taconic.
5. Quartzite unconformable on 6 and 7....................Taconic.
6. Green schists of the Keewatin..........................Archean.
7. Granite or syenite of the Giant's Range...................Archean.

The granite of the Giant's Range is bounded on the north by a belt of crystalline mica-schists and hornblende-schists, and on the south seems to

[1] The Mesabi Iron Range, by H. V. Winchell. In 20th Annual Rep. Minn. Geol. Sur., pp. 11-180.

have a direct transition into the green schists of the Keewatin. The green schist has a nearly vertical cleavage. The schists do not always follow the course of the granite range. They are unconformably covered in many places by the quartzite. The quartzite never has a high dip. Near the base it contains pebbles of quartz and granite, as well as jasper and greenstone. This quartzite is correlated with the Pewabic quartzite of the Gunflint lake, the Pokegama quartzite of the Mississippi river, that of Sioux Falls, South Dakota, and that of Baraboo, Wisconsin. Conformable with the quartzite is the iron ore and taconyte horizon. The strata are siliceous and calcareous, and are banded with oxide of iron in beds of variable length and thickness. The ore is sometimes magnetite and sometimes hematite. To the banded jaspery quartzite associated with the ore the term taconyte is applied. The greenish siliceous slates or cherts constitute a transition stage between the rocks of the iron horizon and the black slates. There is a considerable mixture of greenish material, apparently of eruptive origin. The greater part of the rock is a red, yellow, black, white, or green chert, sometimes having a thickness of 200 or 300 feet. It often has a peculiar brecciated appearance, having been shattered into angular fragments, and recemented by the same amorphous silica. The same fracturing is also visible in the iron ore. The siliceous slates and cherts pass upward into a carbonaceous argillite of great thickness, having a dip varying from the horizontal to 20° to the south or southwest. Locally the dip is as high as 45°, in which case the ore deposits lie close to the green schists. The gabbro flow is over all of the previous strata. The effect of the heat on the molten gabbro was to make the iron ore which already existed in the rocks hard and magnetic. There is good reason to believe that the iron ore deposits in their present condition have been principally formed since the gabbro overflow. The ore deposits occur as regular beds, which lie in almost their original positions, usually having a dip of less than 30° and passing into the jaspery quartzite or taconyte in three directions, and occasionally on all sides. The theory of Irving as to the origin of the Gogebic ores is partially adopted. The quartzite is impervious to surface infiltration. The ore is regarded as produced by chemical replacement of some mineral, chiefly silica, by oxide of iron. As evidence of this, all stages of the process may be seen. Iron carbonate is found in the Mesabi rocks, but it does not appear in sufficient quantity to permit the assumption that the source of the ore was originally a carbonate. The solvent for the silica was probably carbon dioxide, and its source may have been the atmosphere, the black slates, recently decaying vegetation, or the ore deposits higher up the hill. The silica removed from the location of the iron ores has been added to the grains of quartz in the quartzite, has been deposited as chalcedonic and flinty silica, and has been deposited in cracks and fissures in the slate, which lie at a lower elevation, but stratigraphically above the ore. The source of

the iron is believed to have been chemical and mechanical oceanic deposits, which have simply concentrated in the present situation, perhaps from rocks now completely removed by erosion. The water which brought in the iron ore to supply the place of the silica taken away in solution followed the natural drainage courses, either the drainage slopes or else the joints. The Giant's Range is regarded as having been uplifted at the time of the gabbro outflows, and to have been caused by them.

Comments.—The succession of the Mesabi range is almost identical with that given by the reviewer for the Penokee-Gogebic district. At the base of the Penokee series constituting the basement complex are granite, syenite, and various green schists. These correspond to Nos. 6 and 7 of the Mesabi. Resting unconformably upon this basement complex is the quartz slate member, consisting largely of quartzite, corresponding to Winchell's No. 5. Resting conformably on the quartzite is the iron-bearing member, which has two main horizons, the lower carrying the ore bodies, and the other free from ore bodies. This iron-bearing formation of non-fragmental origin consists of cherts, slates, and jaspers, all more or less ferruginous. It evidently corresponds exactly to Winchell's Nos. 3 and 4, his "taconyte" being a new name proposed for ferruginous chert, or what the miners call "soft ore jasper." Overlying the iron-bearing member is the upper slate member, which is identical in character with Winchell's Animikie black slates. Unconformably upon the black slates is the Keweenawan series, which, in the Penokee area, has different characters in different places, but to which Winchell's No. 1 gabbro belongs. There thus appears to be absolute identity as to succession, and also the structural breaks occur in precisely the same horizons in the Penokee and Mesabi districts. The facts given as to the iron ores, apart from theory, correspond in nearly every respect with the occurrences in the Penokee district. The differences are that the basement impervious formation in the Mesabi range is not a dike rock, but the pitching quartzite alone. The source of the iron ore is said to be an oceanic deposit, but while the presence of iron carbonate is asserted, it is denied that it can be assumed that it has been present in sufficient quantity to furnish ore beds. The cherty iron carbonate of the Gogebic range, the source of the ore, was a water deposited sediment.

The presence of three like unconformable series in the Penokee and Mesabi districts, the identical succession of the iron-bearing series, the remarkable similarity of the rocks of each of the corresponding formations, and the nearly identical history of the ore-deposits, is a remarkable instance of like conditions prevailing simultaneously in a geological basin throughout a wide area.

Hulst[1] gives a resumé of the general geology of the Menominee district as explained by Brooks, and gives detailed sections of several of the mines. The descending succession at the Millie Ore Body and Chapin Mine is as follows :

Quartzite	
Jasper	
Quartzite	
Quartzite and jasper	140 feet.
Quartzite, slate, and jasper	
Slate	
Quartzite and slate	
Quartzite and jasper	
Banded ore, containing Millie Ore Body	300 feet
Quartzite and slate	55 feet.
Slate	
Jasper	170 feet.
Ore body	
Gray slate	75 feet.
Ore	
Gray slate	
Jasper	
Gray slate	
Jasper G	185 feet.
Gray slate	
Jasper	
Ore	
Gray slate	
Limestone	

The descending succession in the Pewabic Mine is as follows :

Jasper and ore, containing Pewabic Ore Body	215 feet.
Gray slates	112 feet.
Quartz	
Gray slate	
Quartzite	77 feet.
Quartz and slate	
Slate conglomerate	50 feet.
Red slate	77 feet.
Quartz and gray slate	
Quartzite	
Quartz and sand	
Slate conglomerate	
Quartz conglomerate	116 feet.
Red slate	
Jasper	
Red, gray slate	
Limestone.	

[1] The Geology of that Portion of the Menominee Range East of Menominee river, NELSON P. HULST. In Proceedings Lake Superior Mining Institute for March, 1893, pp. 19-29.

The ore bodies are found in beds of banded lean jasper, which is always an invariable associate of the richer ore, and it may occur anywhere within the jaspery horizon. The rich ore often appears to be a part and parcel of the general stratification of the lean ore encompassing it. Not infrequently one finds spots which are apparently in the transition state from the lean jaspery ore, as though the ore body was charged with a solution, which was gradually dissolving out the silica from the adjacent jasper. There is invariably a notable pitch to the ore bodies, and it is generally to the west at an angle of from 30° to 50°. Connected with some of the ore bodies are well defined hanging or foot-walls of so-called soapstone, but often when there are no well-defined walls, the ore body being found in the jasper, the ore is quite sure to carry a minimum of phosphorus, as exemplified at the Millie, Pewabic, Cyclops, Aragon, and S. E. Vulcan mines. The productive portions of the range appear to be located at the points where the formation has been faulted, eroded deeply, or sharply folded.

Comments.—The sections give additional evidence that in the Menominee district, as in the Marquette, there are two unconformable series. The Chapin, Ludington, and Hamilton appear to belong to the Lower Huronian. The horizon of quartzite, slate and conglomerate is evidently the basal conglomerate of the Upper Huronian. The Mille, Pewabic, and similar ore bodies, are in the Upper Huronian. That the ore bodies occur in disturbed areas, and frequently rest upon soapstone or other impervious formations, accords perfectly with what has been previously ascertained as to the manner of concentration of the Lake Superior iron ores.

Van Hise[1] gives the following as the ascending succession in the iron-producing part of the Marquette district: (1) Basement Complex, consisting of granites, gneisses, schists, and greenstone-conglomerates, the whole intricately intermingled, and the schists intruded by the granites and gneissoid granites; unconformity: (2) Lower Marquette series, having at its base a conglomerate and quartzite formation, upon which rests an iron-bearing formation; unconformity; Upper Marquette series, which looked at broadly is a great shale, mica-slate and mica-schist formation, but it often has at its base quartzites and conglomerates, and several hundred or a thousand feet from its base an iron-bearing formation similar to that of the Lower Marquette series. Included within both the Lower and Upper Marquette series are many basic intrusive dikes and bosses of diabase, and also contemporaneous volcanics, which are largely tufaceous

At the east end of the Marquette district is the Mesnard series, the position of which has not as yet been determined.

[1] The Succession in the Marquette Iron District of Michigan, by C. R. VAN HISE. Bull. Geol. Soc. of Am., Vol. V., 1893, pp. 5–6.

Van Hise[1] describes the Huronian volcanics south of Lake Superior. These include both lavas and tufas interstratified with each other and with contemporaneous clastics. Among the lavas are amygdaloids, the amygdules of which are in certain cases jasper similar to that of the iron formation adjacent, and believed to have been formed at the same jasper forming period. The volcanics are much more altered than those of the Keweenawan. They are found in various places, but the most extensive areas are in the Gogebic district west of Gogebic lake, and in the Michigamme district north of Crystal Falls. In the first locality the series is 7,000 or 8,000 feet in thickness. This great mass of material was piled up, while to the west 700 to 800 feet of the sediments of the iron-bearing formation were accumulating. In this district, therefore, at the same time there was being deposited the ordinary sediments of the area and locally a volcanic series of a wholly different character.

[2]Bayley describes actinolite-magnetite-schist from the Mesabé range of Minnesota. This rock differs from the corresponding schists of the Penokee series only in that quartz is rare and hematite is absent.

C. R. Van Hise.

[1] The Huronian Volcanics South of Lake Superior, by C. R. Van Hise. Bull. Geol. Soc. of Am., Vol. IV., pp. 435–36.

[2] Actinolite-magnetite-schists from the Mesabé Iron Range, in Northeastern Minnesota, by W. S. Bayley. Am. Jour. of Sci., Vol. XLVI., No. 273, Sept., 1893, pp. 176–180.